Dave, thought you might be interested in looking at this thesis. Mike

AN ASSESSMENT OF THE MACROINVERTEBRATE COMMUNITY OF THE BUFFALO NATIONAL RIVER

A Thesis

Presented to

the Faculty of the Graduate School

University of Central Arkansas

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Charles Thomas Bryant

October 1997

PERMISSION

Title____

Department____________________________________

Degree____

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Date

Acknowledgements

I would like to thank fellow graduate students Christina Bradley, Carl Dick and Greg Giuffria for their assistance and encouragement. I also would like to thank Drs. David Dussourd and K. C. Larson for their guidance and critical reviews of the manuscript, and my mentor, Dr. Michael L. Mathis for teaching me most of what I know about aquatic ecology, and for allowing me the opportunity to become involved in this project. In addition, I would like to thank the University of Central Arkansas Biology Department for patiently waiting for me to conclude this thesis. Most importantly, I would like to thank my parents, without whose support none of this would have been possible.

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Introduction

Since the publication of "The River Continuum Concept" (Vannote et al., 1980), lotic ecosystems have been viewed as dynamic systems exhibiting a continuous gradient of change along the length of a stream. Changes in abiotic characteristics down a stream's gradient are accompanied by predictable biotic transformations (Minshall and Bruns, 1985; Hawkins and Sedell, 1981; Culp and Davies, 1982; Gibon and Statzner, 1985; Minshall et al., 1983; Naiman et al., 1987). The biotic and abiotic factors governing ecosystem structure are determined primarily by the climatic conditions, geological history, and evolutionary history of the area through which the stream flows (Culp and Davies, 1982; Minshall et al., 1985; Minshall et al., 1983; Meyer, 1990; Resh et al., 1988; Bott et al., 1985).

The River Continuum Concept (RCC) suggests that community metabolism is predominated by heterotrophy in headwaters, autotrophy in mid-reaches, and a return to heterotrophy in lower reaches (Bott et al., 1985). Heterotrophic organisms occurring in various stream reaches, are adapted to feed on the available food sources. If food resources are predominated by a particular type, then the organisms in the community will be adapted to feed on that type. In headwater streams of forested areas, the riparian canopy restricts the amount of sunlight reaching the stream, limiting primary production (autocthonous). In these small streams, seasonal

inputs of leaf matter produced by riparian vegetation (allocthonous inputs) provide the majority of the food resources flowing through the system (Wallace et al., 1995). Head-water communities are dominated by species (shredders) that utilize these allocthonous inputs as their primary food resources (Vannote et al., 1980; Cummins, 1977). As these large leaf particles (course particulate organic matter or CPOM) are processed by shredding organisms, the particle size of the organic matter is decreased. These smaller particles (fine particulate organic matter or FPOM) are either consumed by the few collectors present in headwater reaches or exported downstream where they are utilized by other communities (Wallace et al., 1995).

As the width of a stream increases along its gradient, the shading effect of the riparian canopy decreases allowing primary productivity to increase. The community of macroinvertebrates that inhabit these mid-reach sites are predominated by species (grazers)that feed on algae and other autotrophic producers (autochthonous inputs) or that utilize the FPOM that is exported from headwater reaches (collector gatherers and filterers) (Vannote et al., 1980; Cummins, 1977).

Further downstream, the width of the system increases further, reducing the influence of the riparian corridor. Increasing depth and turbidity in these large rivers reduce the amount of solar energy available for photosynthesis so that primary production is greatly decreased. The primary food sources for organisms inhabiting these rivers are fine and ultra-fine particulate organic matter (UFPOM) that is exported from upstream reaches due to processing ineffiencies. The predominant group of organisms feeding on these sources are the collector filterers (Vannote et al., 1980; Cummins, 1977).

Predator populations generally comprise similar proportions of the community along the entire length of a stream (Vannote et al., 1980; Hawkins and Sedell, 1981) or vary widely, with no discernible pattern (Minshall et al., 1983; Culp and Davies, 1982). This is because they are not directly dependent on allocthonous or autocthonous vegetable organic matter (Dudgeon, 1989; Hawkins et al., 1982).

Species richness and diversity patterns exhibit predictable changes along the longitudinal profile of a stream. In headwater reaches, substrates of riffles are uniformly large due to the scouring effects of water especially during flood events. Diel and seasonal changes in water temperature are dampened due to the proximity of groundwater inputs and the shading effect of the riparian canopy. Food resources are restricted almost wholly to allochthonous inputs of leaves during the autumn. This relative homogeneity in the habitat provides fewer microhabitats (both spatially and temporally) resulting in lower diversity and richness (Vannote et al., 1980; Cummins, 1977).

In midreaches, substrates are more heterogeneous, consisting of a mixture of boulders, cobbles, gravels, and finer particles. Daily and seasonal fluctuations in water temperature are maximal due to the relatively low volume of water (compared to more downstream sites) and the increased amount of solar radiation reaching the surface (compared to headwaters). Food resources include inputs from both allochthonous and autochthonous sources. Allochthonous inputs are greatest along the shoreline and autochthonous production is more prevalent in the mid-channel of the stream. This heterogeneity in both the biotic and abiotic environment results in an abundance of microhabitats leading to higher levels of species richness and diversity (Vannote et al., 1980; Cummins, 1977).

At downstream sites, substrates are rather homogeneous, dominated by gravel, sand and silt. The volume of water is greater than in the midreaches, dampening diel and seasonal temperature fluctuations. Nearly all food resources in lower reaches of streams are FPOM and UFPOM exported from upstream. The reduction in the number of available microhabitats compared to the midreaches of streams results in decreased species richness and diversity (Vannote et al., 1980; Cummins, 1977).

Disturbances, particularly those from anthropogenic sources, can greatly alter the community structure of a stream, and interrupt the natural stream continuum (Resh et al., 1988; Crunkilton and Duchrow, 1991). If disturbances occur at a frequency and/or intensity that is "outside the predictable range" to which organisms in any given system are adapted, then changes in community structure can occur (Resh et al., 1988). Disturbance that has been shown to impact community structure include natural disturbances such as spates (floods) (Cummins, 1977; Resh et al., 1988; Power et al., 1988; Minshall et al., 1985), droughts (Boulton et al., 1992; Resh et al., 1988; Minshall et al., 1985; Power et al., 1988; Iverson et al., 1978; Vannote et al., 1980) and fire (Richards and Minshall, 1992; Malmqvist and Otto, 1987), and anthropogenic disturbances like sedimentation (Lemly, 1982; Tuchman and King, 1993; Power et al., 1988; Resh et al., 1988; Gurtz and Wallace, 1984; Graham, 1990), canopy removal (Tuchman and King, 1993; Gurtz and Wallace, 1984; Minshall et al., 1985; Resh et al., 1988; Hawkins et al., 1982), impoundment (Crunkilton and Duchrow, 1991; Ziser, 1985; Resh et al., 1988; Minshall et al., 1985), channelization and gravel-mining (Minshall et al., 1985; Tuchman and King, 1993; Resh et al., 1988; Crunkilton and Duchrow, 1991; Petersen, 1991), and organic enrichment (Lemly, 1982; Crunkilton and Duchrow, 1991; Tuchman and King, 1993; Hilsenhoff, 1987; Stewart and Robertson, 1992; Petersen, 1991; Brown et al., 1983). Natural disturbances act as reset mechanisms in the community, leaving communities in earlier states of succession than before disturbances. The changes they cause in community structure are generally short-lived if the affected catchment is allowed to recover (Power et al., 1988). These types of disturbances are dynamic processes that characterize and shape communities over evolutionary time, and the organisms living within these communities have for the most part adapted to these seasonal and stochastic events (Cummins, 1977; Resh et al., 1988; Power et al., 1988; Vannote et al., 1980). Human activities often result in permanent or semipermanent alterations of the environment (clearing of forests for agriculture or land development, channelization, wastewater discharge, etc.). These anthropogenic disturbances can cause the degradation of water quality resulting in the loss or reduction of some taxa and increases in others (Petersen, 1991; Tuchman and King, 1993). These disturbances can cause pollution intolerant taxa to disappear, and this may be reflected by biotic index calculations from impacted streams when compared to pristine streams (Petersen, 1991).

Many members of the Ephemeroptera, Plecoptera, and Trichoptera (EPT) are pollution-sensitive species, and because of this are utilized in community structure metrics that indicate water quality. Some dipteran species are also pollution-sensitive, but the dipterans are generally more pollution tolerant than the EPT (Hilsenhoff, 1987; Lenat, 1993; Brown et al., 1983). These four orders comprise the bulk of the taxa for which pollution tolerance values are available.

The River Continuum Concept has been evaluated in a wide variety of biomes, and has been found to be more applicable in some than in others (Brussock and Brown, 1991; Statzner and Higler, 1985; Winterbourne et al., 1981). Because of these discrepancies, the RCC has been criticized for being too simplistic to apply to all lotic ecosystems. However, it has been tested by many researchers over the past decade and generally has been accepted as a reliable framework for describing the qualities and characteristics of lotic systems around the globe (Culp and Davies, 1982; Minshall et al., 1985; Garman and Moring, 1991; Meyer, 1990; Bott et al., 1985; Naiman et al., 1987; Bruns and Minshall, 1985; Minshall et al., 1983; Hawkins and Sedell, 1981; Gibon and Statzner, 1985).

In this investigation, a baseline inventory of the Buffalo National River was conducted in order to characterize macroinvertebrate community structure at various sites along the length of the stream.

The specific objectives of this study were:

1. To examine the macroinvertebrate community structure in fourth and fifth order reaches of the Buffalo National River. If the Buffalo River conforms to the River Continuum Concept (RCC), longitudinal changes in community structure (taxonomic composition, functional structure, and species diversity and richness) should be evident. For instance, functional changes that might be expected include a decrease in the relative abundance of shredders and an increase in the relative abundance of collector gatherers/filterers along the longitudinal profile of the stream. If the river does not conform to the RCC, there should either be no differences in the community structure at the various sites or changes should not occur in a predictable manner as suggested by the RCC.

2. To collect baseline data of the macroinvertebrate community of the Buffalo River. The Buffalo River is probably the most unimpacted stream in the Ozark region (Mott, 1991). Data drawn from this investigation should provide baseline information suggesting what levels of macroinvertebrate

community structure should be expected naturally in other streams in the region.

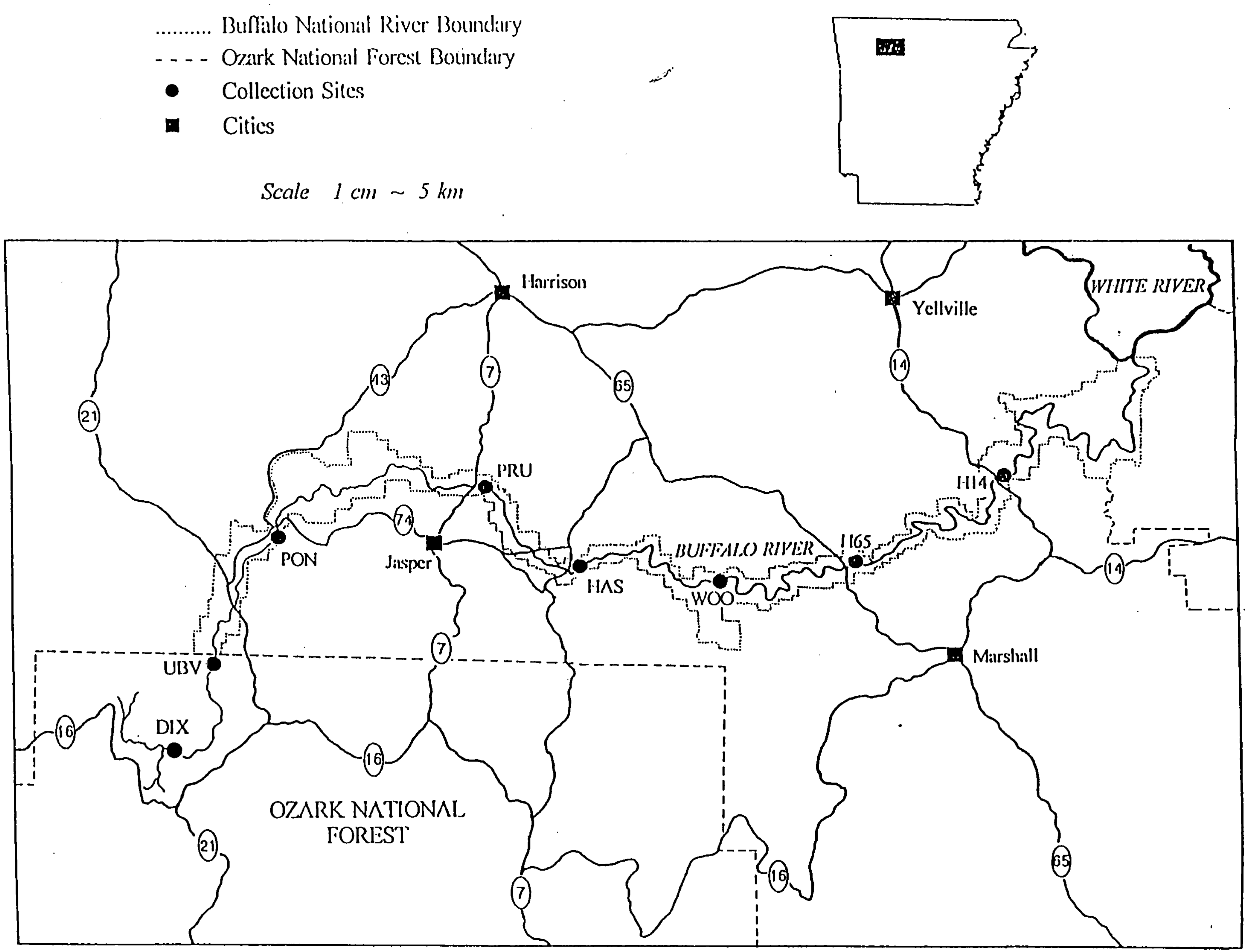
3. To determine if any significant impacts have occurred along the length of the river. Water quality in the Buffalo River generally is exceptional, but certain parts of the river (Boxley Valley and the middle section of the river) have exhibited declines in water quality related to agriculture occurring along the river and its tributaries (Mott, 1991). Although the level of pollution entering into the river appears to be relatively low based on physicochemical data (Mott, 1991), changes in the community structure may have occurred and should be detectable using a variety of pollution indices.

Study Area

The Buffalo River originates in the Boston Mountains of Arkansas and flows northeasterly along the southern border of the Springfield-Salem Plateau before its confluence with the White River near Cotter, Arkansas. The topography of the river's watershed includes characteristics of both the Boston Mountain and Springfield-Salem Plateau physiographic regions. Sandstones and shales of Pennsylvanian age are found in the upper reaches of the river; limestone and dolomite formations of Ordovician age are more prevalent in the lower reaches (Mott 1991). The rock strata in both regions are horizontal and have been cut deeply by many streams. The upper watershed is located in the Boston mountains and has a rugged terrain with steep slopes, making land largely unsuitable for agriculture (12% in agricultural production; 88% forest). In contrast, the mid and lower reaches are more suitable for agriculture (62% agriculture; 37% forest) (ADCP&E 1991).

Eight sites along 130 river miles were selected as sampling stations (Fig. 1). These sites, listed in order from upstream to downstream are Dixon Ford (DIX), Upper Boxley Valley (UBV), Ponca (PON), Pruitt (PRU), Hasty (HAS), Woolum (WOO), U.S. Highway 65 (H65), and Arkansas Highway 14 (H14). The upper four sites are fourth order; the four downstream sites are fifth order. Although the sample sites covered only two stream orders, there are marked changes in gradient and

Figure 1. Eight macroinvertebrate sampling sites along 130 river miles of the Buffalo National River. DIX (Dixon Ford), UBV (Upper Boxley Valley), PON (Ponca), PRU (Pruitt), HAS (Hasty), WOO (Woolum), H65 (U.S. Highway 65), H14, (Arkansas Highway 14).



Buffalo National River Boundary
Ozark National Forest Boundary
Collection Sites
Cities
Scale 1 cm ~ 5 km
Harrison
Yellville
WHITE RIVER
PRU
H14
H65
BUFFALO RIVER
PON
Jasper
HAS
WOO
Marshall
UBV
DIX
OZARK NATIONAL FOREST
21
43
7
65
14
74
16

link magnitude (number of first-order tributaries upstream from a certain point) with increasing distance from source (Table 1).

The total size of the Buffalo River watershed is approximately 1323 square miles. Drainage areas of the sample sites for this project ranged from under 50 square miles to 1047 square miles. The annual mean discharge (1940 to 1993) at the U.S. Highway 65 bridge is 1046 cubic feet/second with mean monthly discharges ranging from 153 cubic feet/second in September to 2191 cubic feet/second in April (U.S. Geological Survey Report AR-93-1)(Fig. 2). Records indicate that samples gathered for this investigation were collected in a year with lower than average discharge (Fig. 3).

Table 1. Measures of position, size, and gradient of the eight sampling sites on the Buffalo National River.

SITE	DISTANCE FROM SOURCE (KM)	ORDER	LINK MAGNITUDE	GRADIENT (M/KM)
DIX	11.1	4	13	7.7
UBV	32.9	4	35	5.6
PON	45.9	4	59	2.3
PRU	84.3	4	110	1
HAS	96.9	5	229	1
WOO	121.2	5	287	0.9
H65	148.9	5	433	0.6
H14	191	5	602	0.6

Figure 2. Monthly mean discharge for water years 1940-1995 from the Buffalo National River near St. Joe, Arkansas (USGS, 1993).

MONTHLY MEAN DISCHARGE FOR WATER YEARS 1940-1995
BUFFALO RIVER NEAR ST. JOE

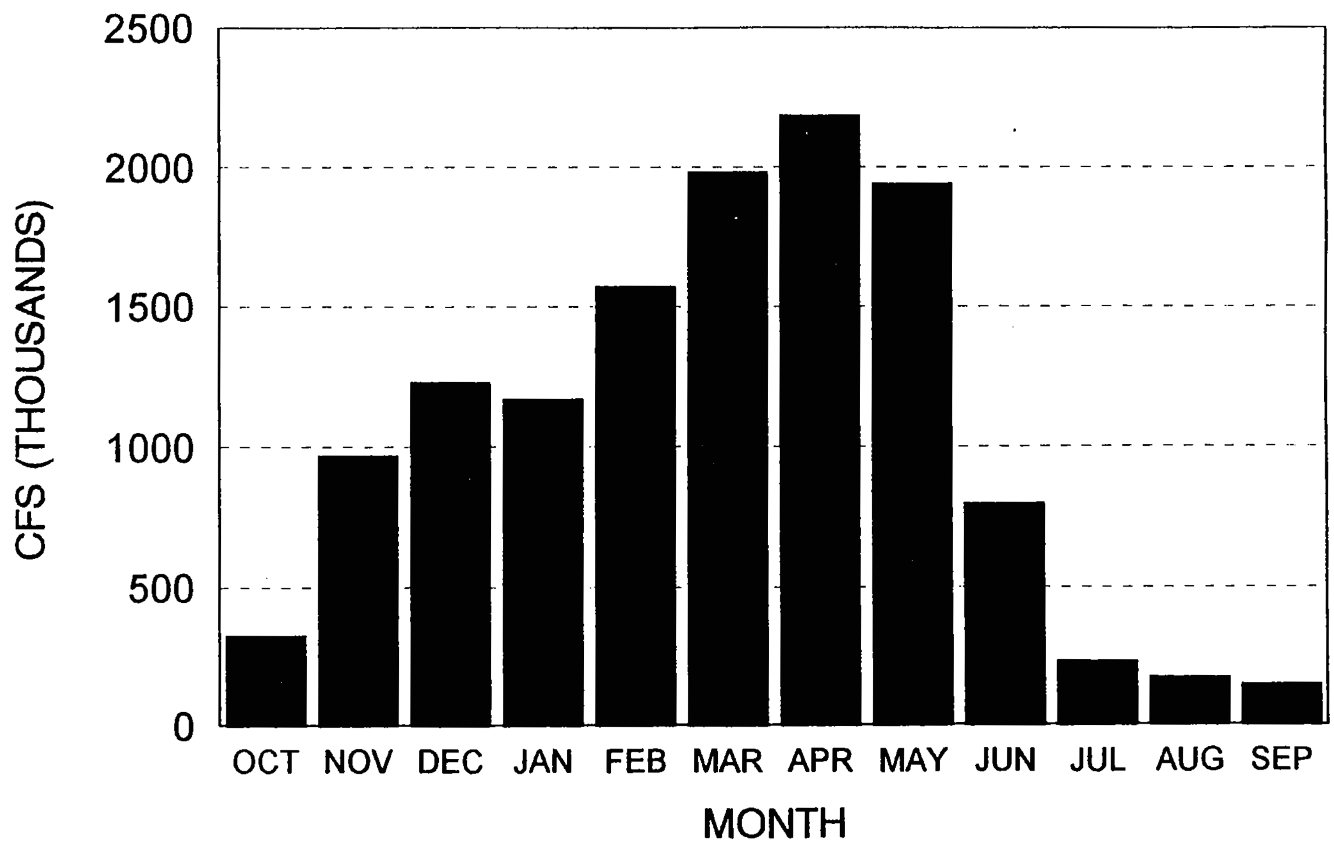
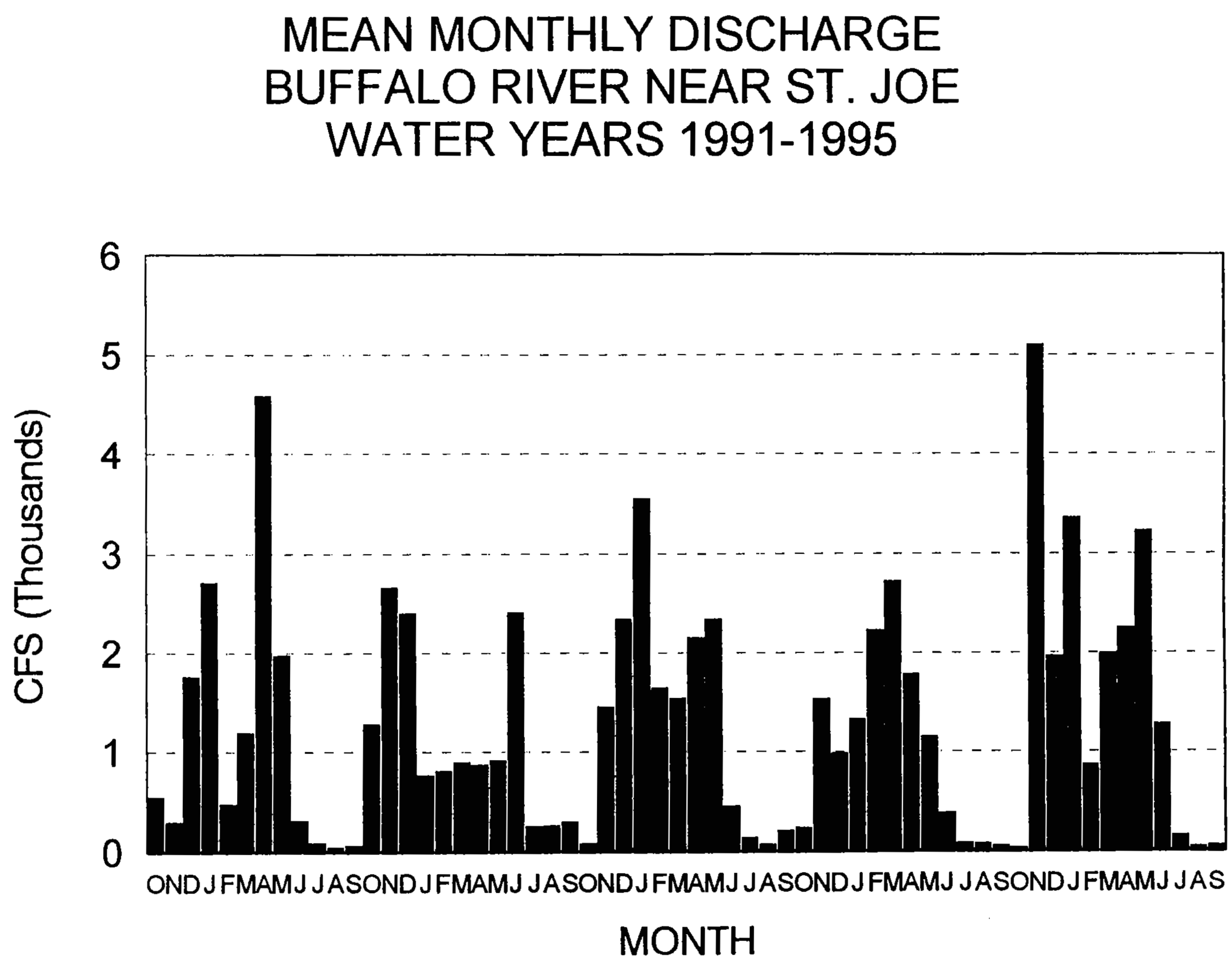


Figure 3. Mean monthly discharge of the Buffalo National River for water years 1991-1995 near St. Joe, Arkansas (Mott, 1995).



MEAN MONTHLY DISCHARGE
BUFFALO RIVER NEAR ST. JOE
WATER YEARS 1991-1995
6
5
4
3
2
1
0
CFS (Thousands)
ONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJASONDJFMAMJJAS
MONTH

Methods and Materials

Invertebrates were collected quarterly for one year in June 1993 (summer), October 1993 (autumn), December 1993 (winter), and March 1994 (spring), using a modified Hess sampler (0.086 m2, 363 *um* mesh). In order to minimize sample variance only riffles were sampled. Five samples were collected at each site on each sampling date by raking/digging the substrate 200 times with a hand-held garden rake to a depth of approximately 10 cm. Attached invertebrates (many with cases or shells) were removed from larger substrate particles by hand before raking. Each sample was transferred to a 1-pint Mason jar and preserved in Kahle's fixative (Wiggins, 1978). In the laboratory, macroinvertebrates were sorted from the debris, identified to the lowest taxon practical, enumerated, and stored in vials of 70% ethanol. The numerical data were used to calculate a variety of measures of community structure including taxa richness (Margelef's Index), taxa diversity (Shannon's Index), functional composition and taxonomic composition [including EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa richness, percent EPT (%EPT) (percent of organisms collected that are EPT), EPT:D (ratio of Ephemeroptera, Plecoptera, Trichoptera:Diptera), percent Diptera (%DIP), percent chironomid (%CHIR), and percent dominant (%DOM)]. A biotic index was calculated for each site using the pollution tolerance values of Lenat (1993). Margelef's Index was calculated with the formula,

$$d=s-1/\ln N$$

where d is the number of species occurring divided by the natural logarithm of the total number of organisms collected. This index accounts for variation in the number of organisms collected per sample. Shannon's Index was calculated using the formula,

$$H'=(N \log N-\sum ni \log ni)/N$$

where N is the number of individuals and n is the number in the ith species. Data for all metrics were tested for normal distributions and equal variances (Systat 5.0 for Windows) to determine the appropriate (parametric or nonparametric) statistical analyses to be used. Fully factorial Two-way Analysis of Variance (Systat 5.0 for Windows) was used to determine if significant differences occurred between sites and season and the interaction of site and season for the metrics. When interaction terms were significant, one-way Analysis of Variance (Systat 5.0 for Windows) was used to determine if significant differences existed between sites for each season for the above metrics. Tukey tests were run to determine where significant differences occurred (Systat 5.0 for Windows). Percentage data (e.g. collector-filterers, shredders, scrapers, predators, abundance and EPT:D) were log-transformed [ln (x+1)] for analysis, but were plotted as raw percentages. Pearson correlations between seasonal means of biological metrics, and physicochemical measurements were performed using Systat 5.0 for Windows. Physicochemical and microbiological characteristics used for analysis were collected by the U.S. Park Service and U.S. Geological Survey for the seven downstream sites and include discharge, pH, temperature, dissolved nitrate nitrogen, orthphosphate, conductivity, turbidity, dissolved oxygen, and fecal coliform concentration (Mott, 1991; USGS, 1993).

Physical habitat characteristics (including percent canopy cover, percent embeddedness, substrate composition, and vegetational characteristics) were measured on three riffles in the vicinity of each site (including the sample riffle) in July 1996. Percent canopy cover was measured with the use of a densiometer at the 0.25, 0.50, and 0.75 channel widths. Percent embeddedness was measured by randomly selecting cobble-size substrate stones (20 per riffle) and visually estimating the percentage of the stone embedded in the substrate sediments. Substrate composition was measured along three 50 meter linear (along stream gradient) transects through three riffles. The substrate particle size under each meter mark was noted (bedrock, boulder >30 cm, cobble 8-30 cm, gravel 1-8 cm, sand 0.1-1 cm, and fines <0.1 cm), and percentages of each category calculated at each site. Vegetational characteristics were measure by visually estimating the percentage of algal mats, mosses, emergent vegetation, and detritus observed along the same 50 meter transects. Results of these measurements were statistically analyzed for differences among sites using ANOVA and nonparametric Kruskal-Wallis ANOVA for percent bedrock and boulder which lacked normal distribution.

Results

Physical, Chemical, and Microbiological Metrics

All sites were either fourth or fifth order, but differed considerably in physical characteristics (Figs. 4-7). Discharge, conductivity, pH, and temperature (Figs. 4 and 6) increased progressively along the longitudinal gradient of the stream. Substrate size decreased along the stream gradient (Fig. 5). Bedrock occurred only at DIX ($p<0.01$, DF=7), and the amount of boulder substrate found at UBV was significantly greater than that found at the other sites ($p<0.000$, DF=7)). The amount of cobble and sand varied extensively among the sites, exhibiting no significant differences. The amount of gravel substrate increased significantly along the length of the stream ($p<0.001$, DF=7). Percent embeddedness varied little among the sites with the exception of WOO, which was more embedded than UBV ($p<0.043$, DF=16)(Fig. 7). UBV had a significantly greater amount of mosses than the sites downstream ($p<0.001$, DF=7), and the amount of emergent vegetation increased significantly from DIX through the middle sites ($p<0.004$, DF=7) and then decreased (Fig. 7). There were no significant differences in the amount of canopy cover (not shown), algal mats, and detritus among the sites.

Nitrate nitrogen concentrations were elevated during the winter and spring at the three lower sites compared to those

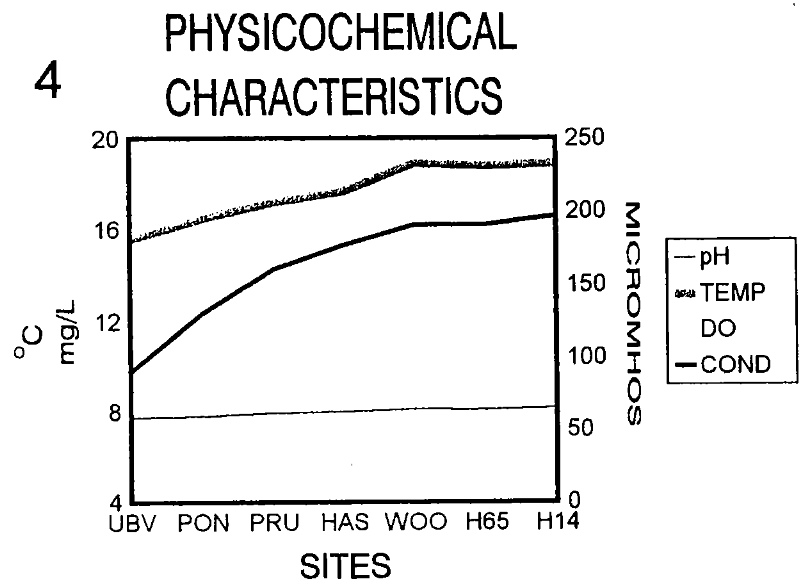
Figure 4. Mean pH, temperature, dissolved oxygen, and conductivity of seven sites along the Buffalo National River (Mott, 1995).

Figure 5. Substrate composition of eight sites along the Buffalo National River.

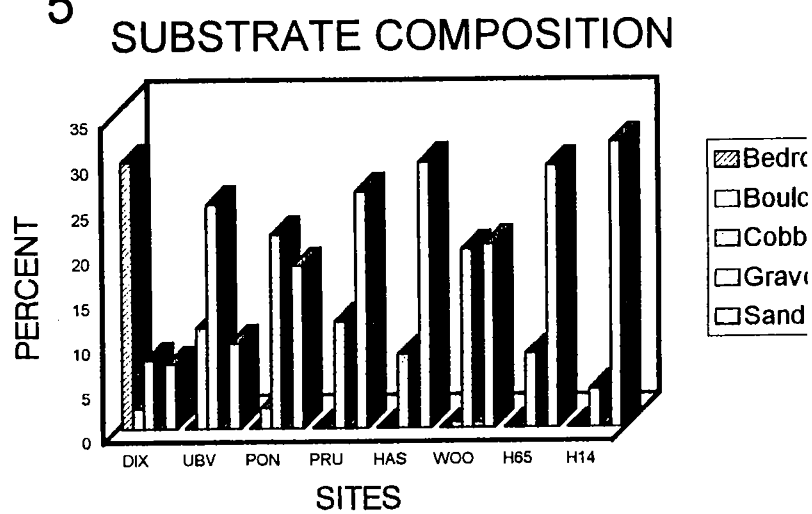
Figure 6. Mean discharge at seven sites along the Buffalo National River (USGS, 1993).

Figure 7. Habitat characteristics at eight sites along the Buffalo National River.

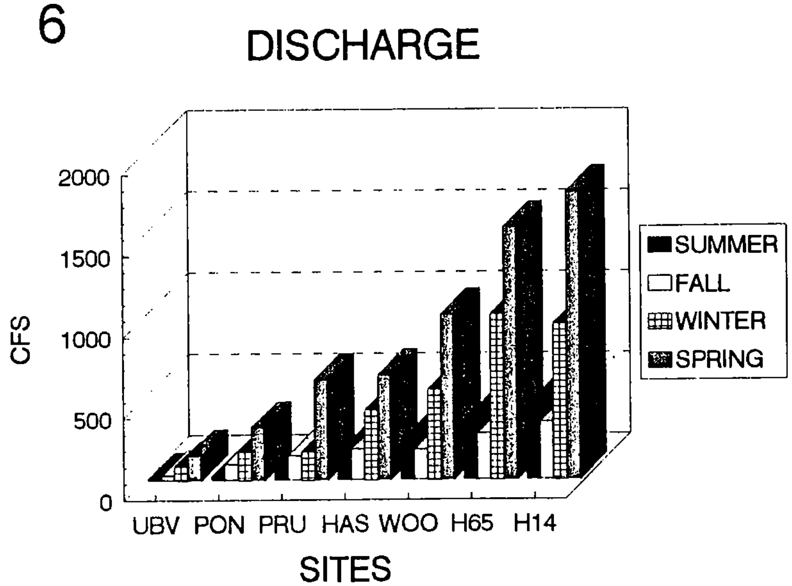
4


PHYSICOCHEMICAL CHARACTERISTICS
20
16
12
8
4
°C
mg/L
250
200
150
100
50
0
MICROMHOS
pH
TEMP
DO
COND
UBV PON PRU HAS WOO H65 H14
SITES

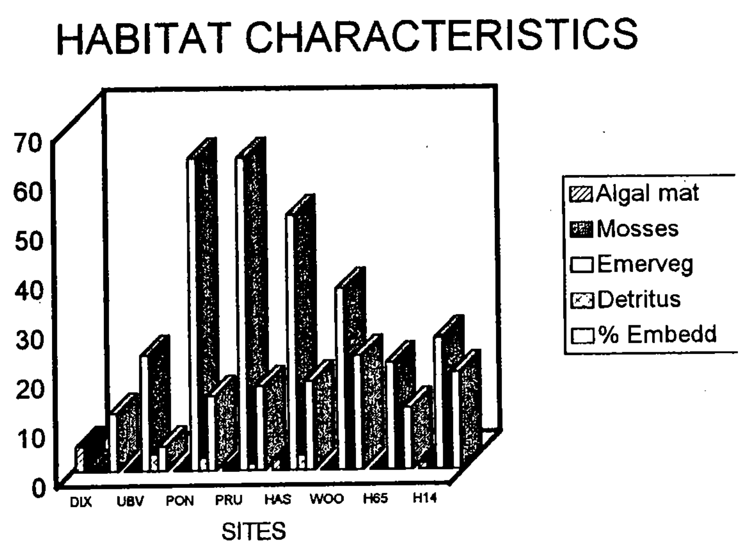
5


SUBSTRATE COMPOSITION
35
30
25
20
15
10
5
0
PERCENT
Bedrc
Boulc
Cobb
Grav
Sand
DIX UBV PON PRU HAS WOO H65 H14
SITES

6


DISCHARGE
2000
1500
1000
500
0
CFS
SUMMER
FALL
WINTER
SPRING
UBV PON PRU HAS WOO H65 H14
SITES

7


HABITAT CHARACTERISTICS
70
60
50
40
30
20
10
0
Algal mat
Mosses
Emerveg
Detritus
% Embedd
DIX UBV PON PRU HAS WOO H65 H14
SITES

located upstream, but not significantly (Fig. 8). Fecal coliform concentrations were significantly higher at PON than all other sites throughout the year ($p<0.001$) (Fig. 9), but nitrate nitrogen concentrations were only slightly elevated at this site compared to those located both immediately upstream and downstream. Orthophosphates were significantly higher at UBV than at HAS in summer ($p<0.032$) (Fig. 10).

Taxonomic Overview

A total of 87,664 organisms were collected and identified during the course of this investigation. Specimens collected represented 7 phyla, 9 classes, 20 orders, and over 50 families (see Appendices 1-4). Members of the arthropod class Insecta were the most common organisms collected. Within this class, the Ephemeroptera were dominant numerically with the family Heptageniidae being best represented with seven genera. Dipterans also occurred in high numbers with the Chironomidae making up the largest part of this order. The orders Plecoptera and Trichoptera were collected in nearly equal numbers and made up large parts of most samples. Coleopterans were less numerous and were represented primarily by the families Elmidae and Psephenidae. Other higher-level taxa that occurred in lesser numbers included the crustacean orders Amphipoda and Isopoda, the Hydracarina (Class Arachnida), Annelida, and Gastropoda (see Appendix 1).

Taxa Richness, Diversity and Composition

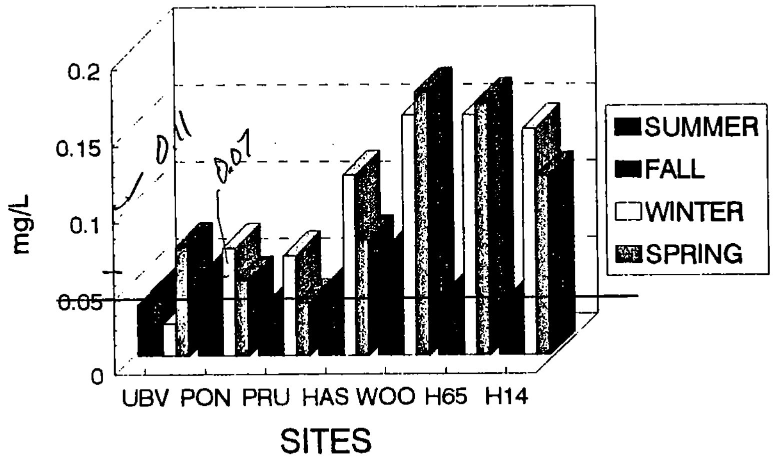
Taxa richness, diversity, and composition varied greatly

Figure 8. Mean NO_3 for four seasons from seven sites along the Buffalo National River (Mott, 1995).

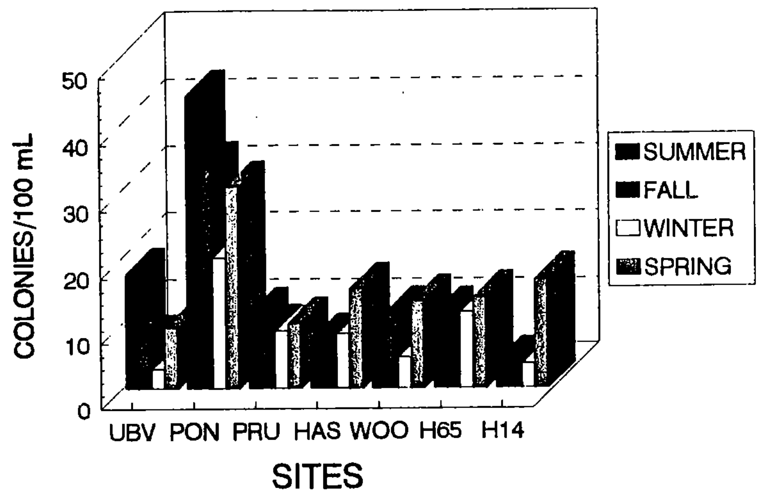
Figure 9. Mean fecal coliforms for four seasons from seven sites along the Buffalo National River (Mott, 1995).

Figure 10. Mean OPO^4 for four seasons from seven sites along the Buffalo National River (Mott, 1995).

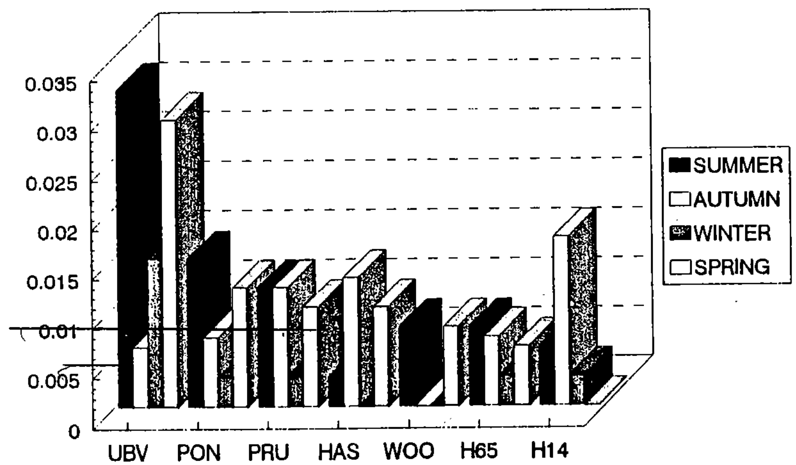
8 NITRATES



9 FECAL COLIFORMS



10 ORTHOPHOSPHATES



among the sites throughout the year. Two-way ANOVA indicated that there were significant differences among the sites for almost all dependent variables. However highly significant interaction terms (site x season) indicated that no consistent patterns occurred among the sites during different seasons and that results for each metric must be evaluated seasonally. With the exception of summer, richness, diversity, EPT:D, and EPT taxa exhibited a similar pattern among the eight sites (Figs. 11-14). Values were lower at DIX than sites immediately downstream, increased through PON and/or PRU, decreased at Hasty and WOO and then increased at H65 and H14. A similar, but weaker pattern was evident for %EPT (Fig. 15). Values for %CHIR and %DOM did not exhibit longitudinal patterns, but in general were significantly higher at WOO than upstream and downstream sites (Figs. 16 and 17). %DIP exhibited a similar pattern as %CHIR and %DOM, except that there were large numbers at DIX in three seasons as well as greater values at downstream sites in three seasons (Fig. 18). Abundance was significantly greater downstream in three seasons (Fig. 19).

Functional Group Metrics

Functional group composition varied tremendously with season and location (Table 2-5); (Fig. 20). The relative abundance of shredders was significantly greater upstream than downstream except during spring when numbers were low at all sites and during winter when high numbers of shredders occurred at most sites. The relative abundance of scrapers

Figure 11. Mean species richness for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

11

MARGALEF'S INDEX

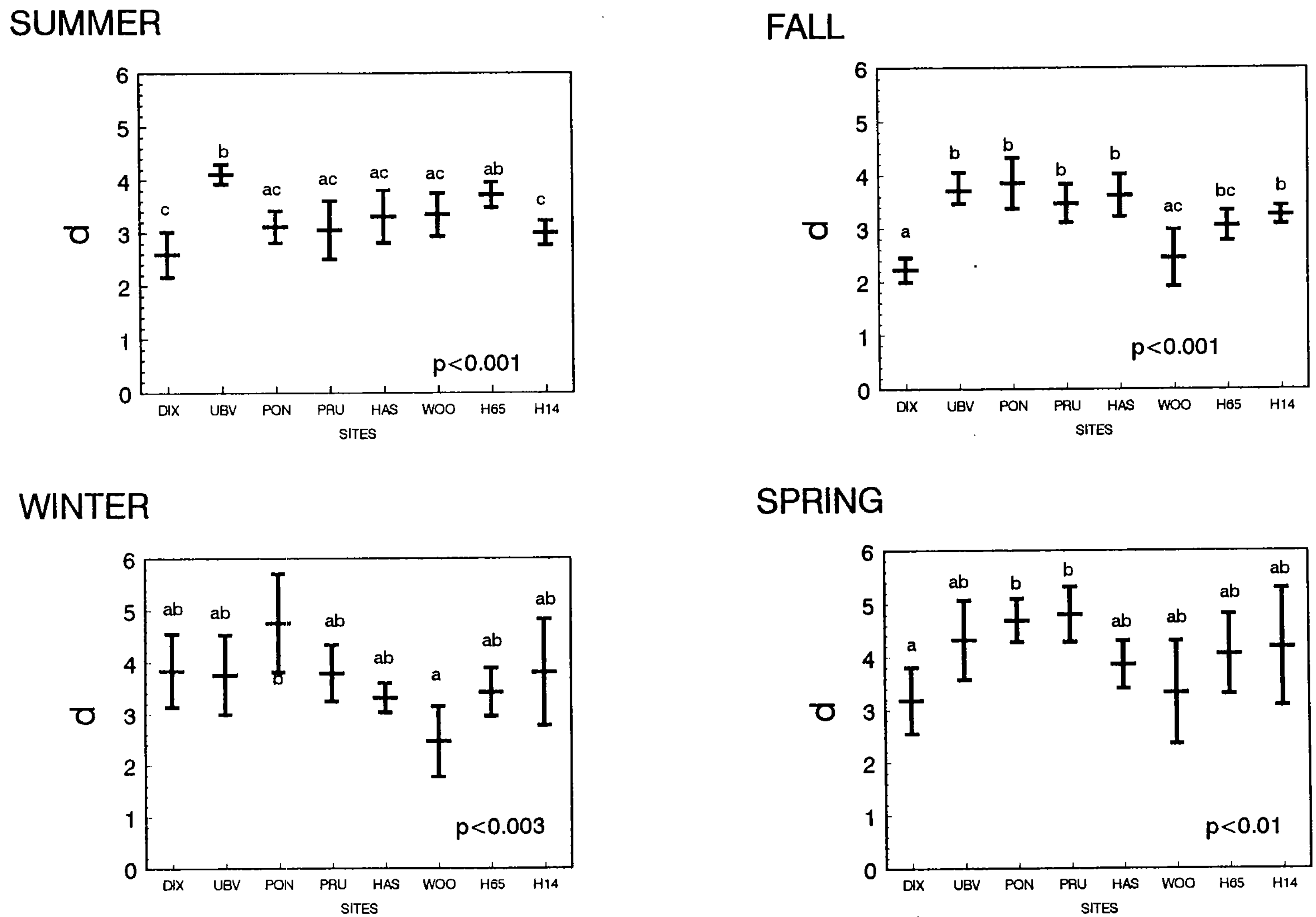
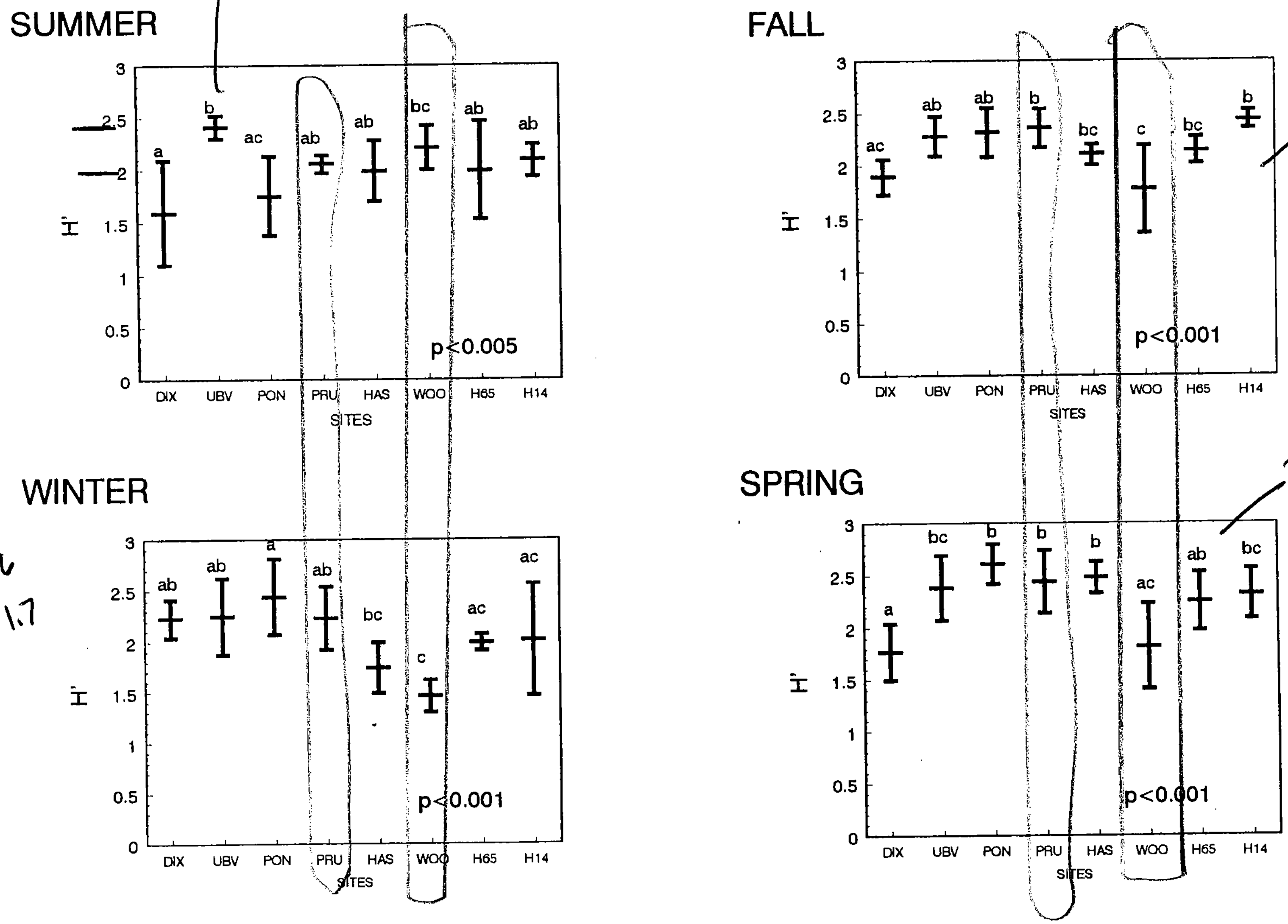


Figure 12. Mean species diversity for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

12 SHANNON'S INDEX

Summer
R3 2[illegible] → 2.3
R5 2 → 2.5



R3 2.2 → 2.6
R5 1.3 → 2.2

R3 2.1 → 2.7
R5 1.3 → 2.2

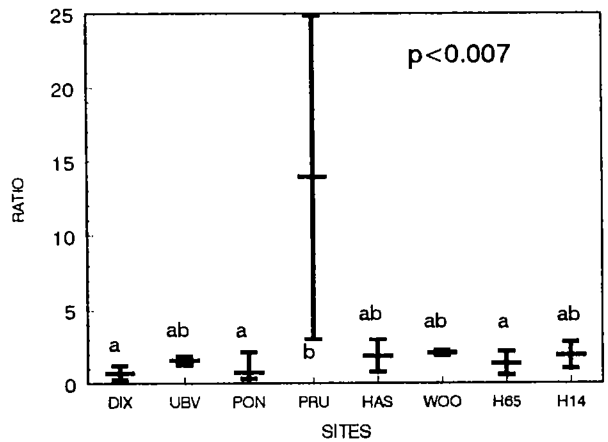
R3 1.9 → 2.6
R5 1.3 → 1.7

Figure 13. Mean EPT:D (the ratio of Ephemeroptera, Plecoptera, and Trichoptera/Diptera) for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

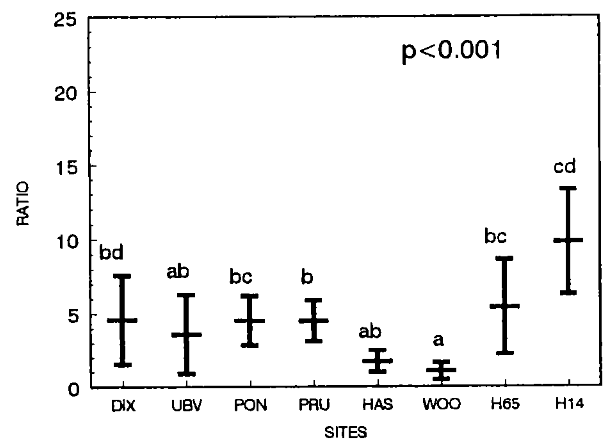
13

EPT:D

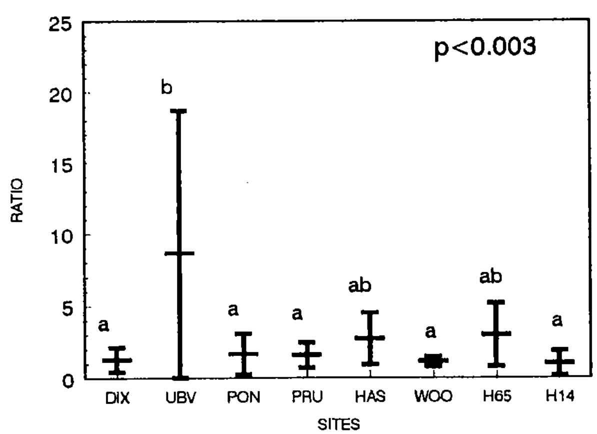
SUMMER



FALL



WINTER



SPRING

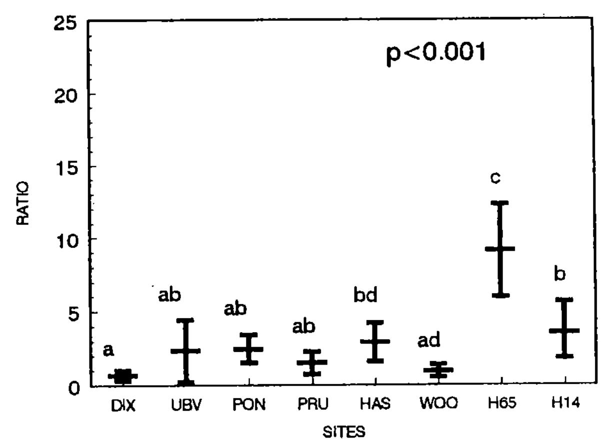
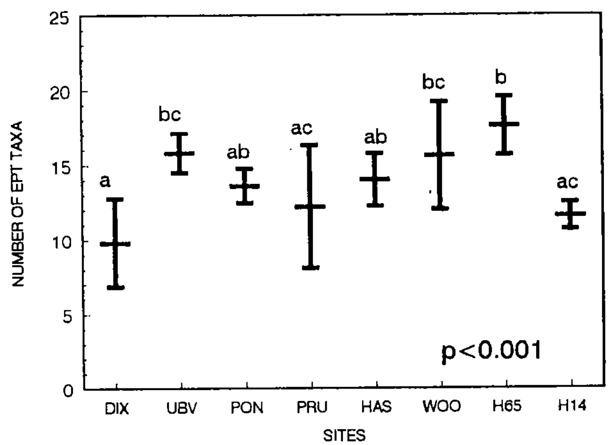


Figure 14. Mean EPT Taxa (the number of taxa that were Ephemeroptera, Plecoptera, or Trichoptera) for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

14

EPT TAXA

SUMMER



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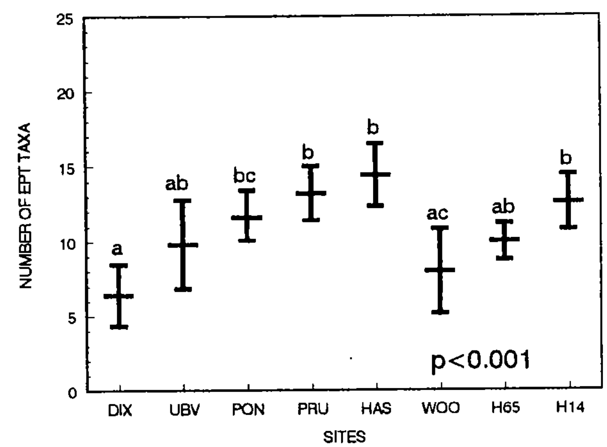

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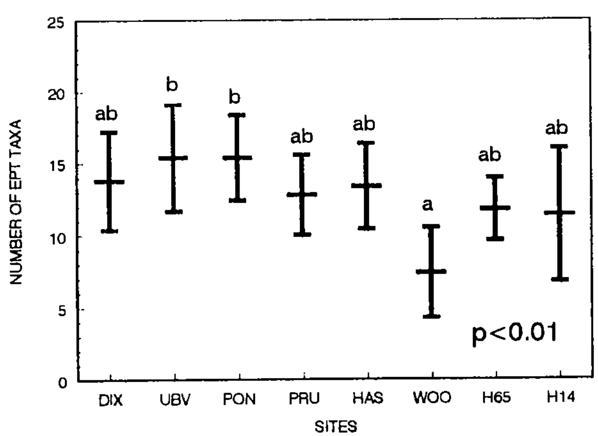

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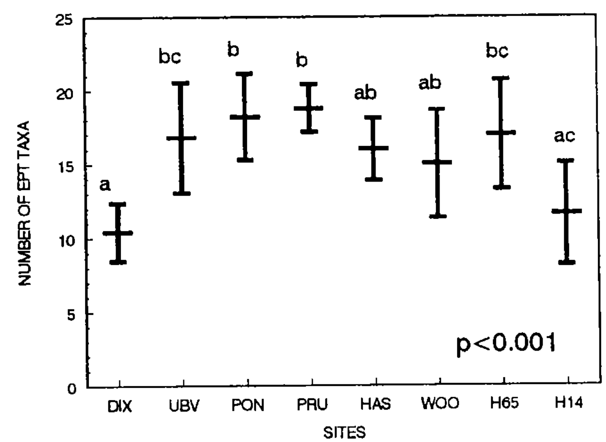
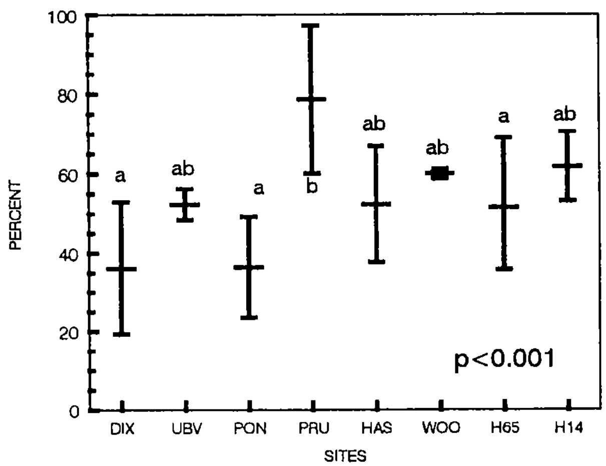


Figure 15. Mean percent EPT (percentage of organisms that were Ephemeroptera, Plecoptera, and Trichoptera. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

15

PERCENT EPT

SUMMER



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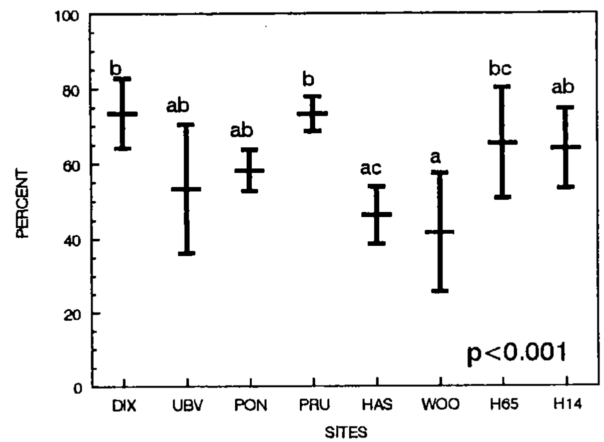

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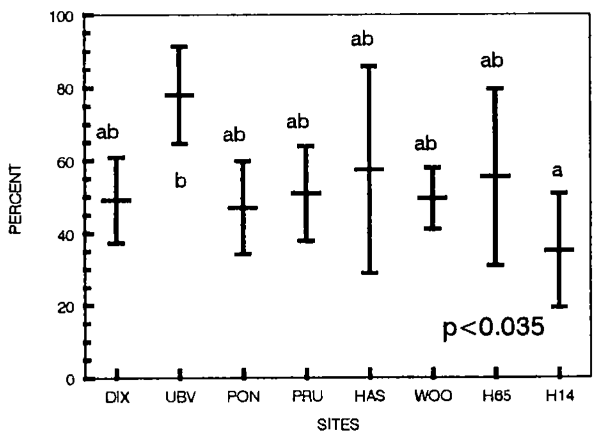

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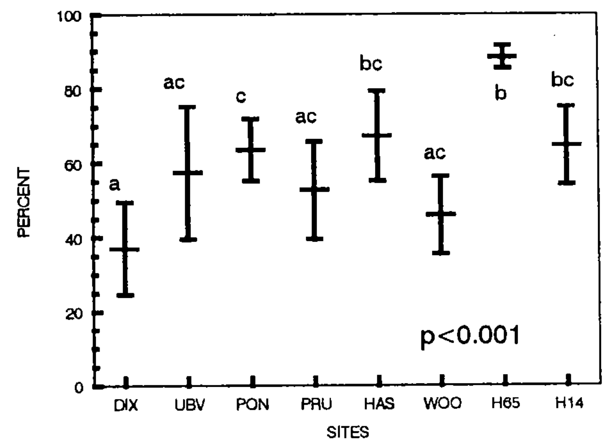


Figure 16. Mean percent chironomids (percentage of organisms that belong to the family Chironomidae: Diptera) for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

16 PERCENT CHIRONOMIDS

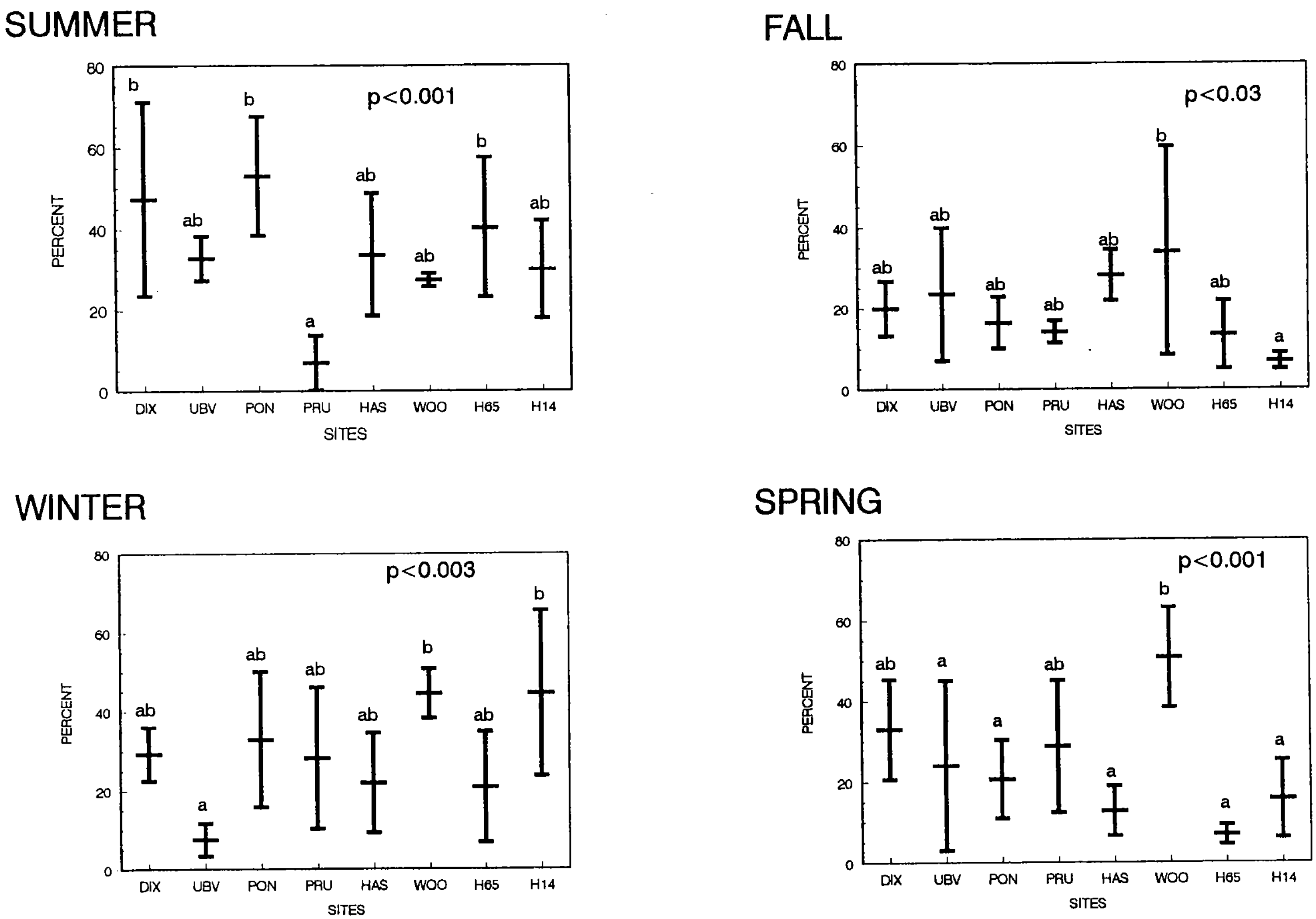
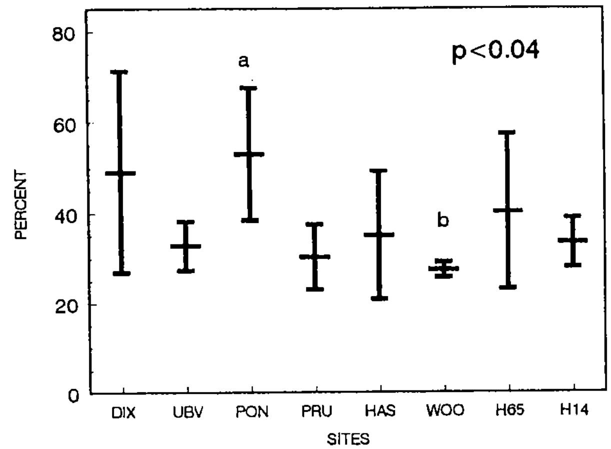


Figure 17. Mean percent dominant (percentage of organisms that belong to the dominant taxa) for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

17 PERCENT DOMINANT

SUMMER



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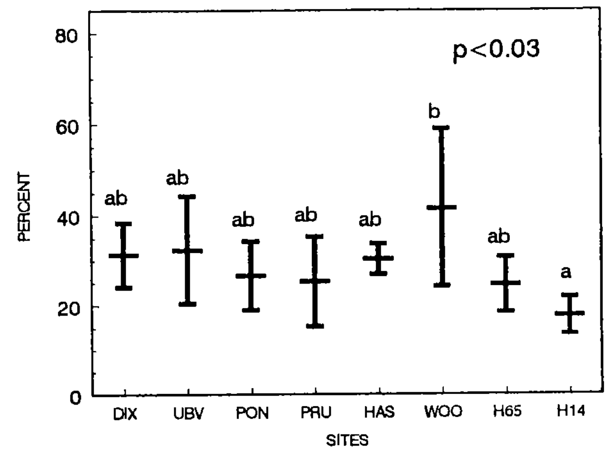

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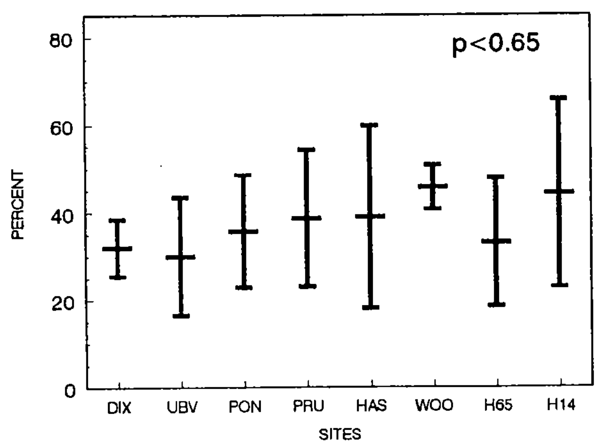

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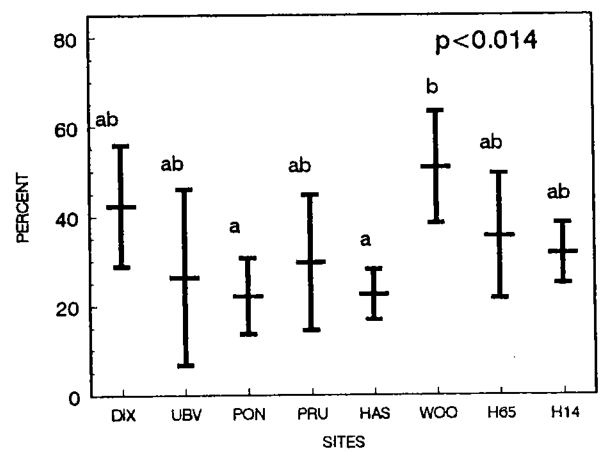


Figure 18. Mean percent Diptera (percentage of organisms that belong to the order Diptera) for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

18

PERCENT DIPTERA

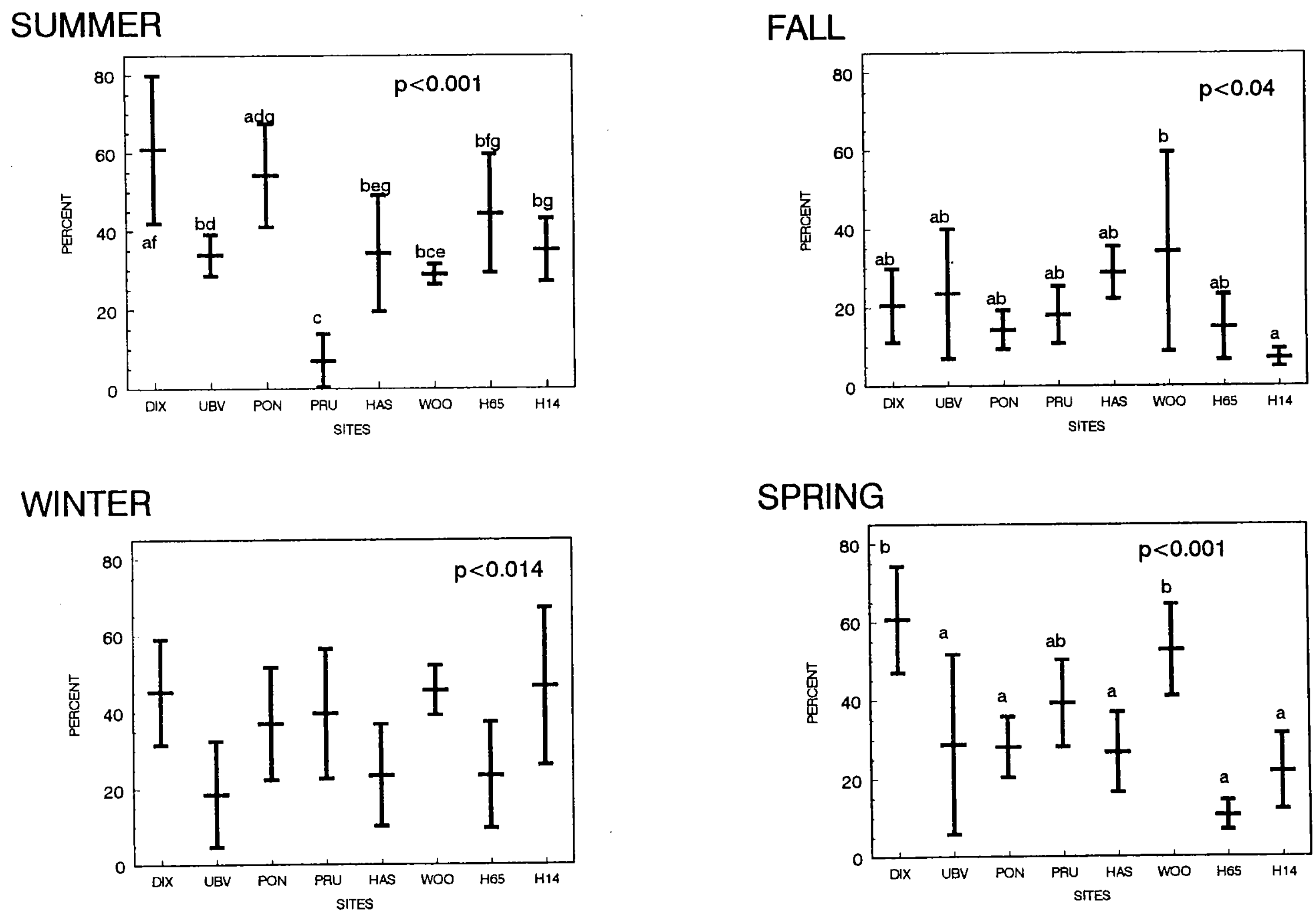
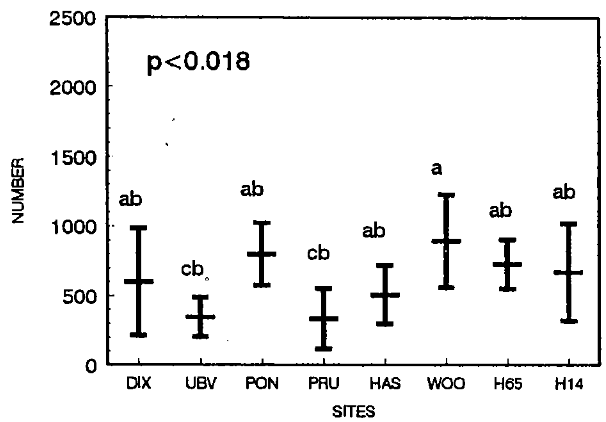


Figure 19. Mean abundance (number of organisms collected) for four seasons at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

19 ABUNDANCE

SUMMER



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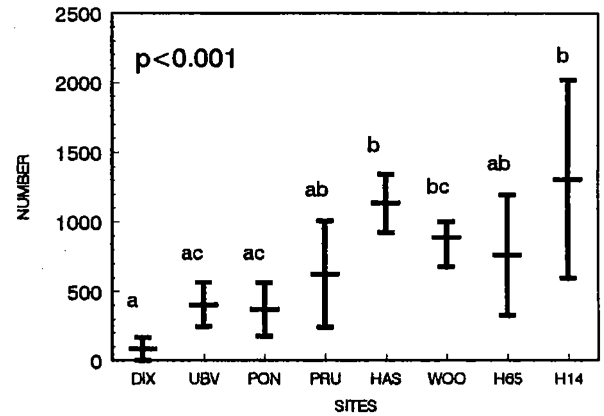
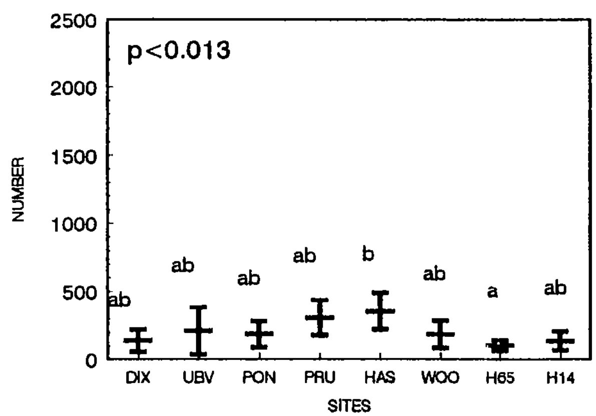


WINTER



SPRING

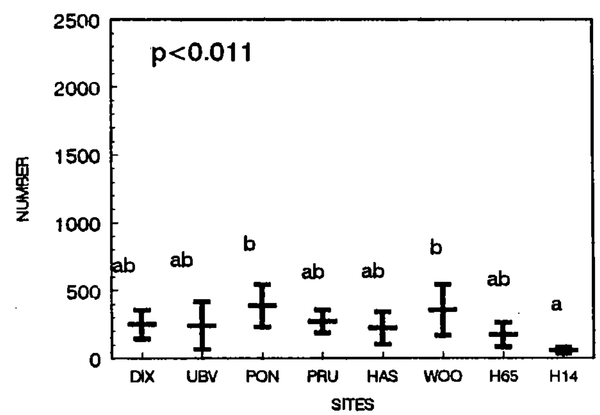


Table 2. Mean summer functional group composition of eight sites of the main channel of the Buffalo National River. Means for each metric are followed by standard error in parentheses. Significant differences are indicated by a superscript. FG (functional group), SHR (shredders), SCR (scrapers), PRED (predators), CG (collector-gatherers), CF (collector-filterers). N=5. Alpha=.05.

FG	DIX	UBV	PON	PRU	HAS	WOO	H65	H14
SHR	10.51 (3.37)[1]	1.39 (0.28)	0.36 (0.12)	0.68 (0.51)	0.83 (0.44)	0.32 (0.15)	1.84 (0.82)	0.03 (0.03)
SCR	9.21 (3.22)[2]	12.41 (1.55)[3]	14.98 (2.39)[4]	48.57 (6.74)	34.93 (6.19)	36.76 (6.22)	28.84 (3.94)	36.14 (2.27)
PRED	16.5 (3.26)[5]	14.1 (1.1)[6]	13.26 (1.41)[7]	4.86 (1)	15.56 (2.88)	10.34 (1.21)	9.95 (0.84)	8.23 (0.96)
CG	53.46 (9.49)	48.61 (4)	56.18 (5.81)	18.7 (3.95)[8]	37.69 (5.97)	31.3 (0.97)	43.27 (7.25)	37.36 (2.34)
CF	9.12 (8.5)	16.39 (4.28)	13.29 (3.94)	17.26 (7.33)	9.53 (4.61)	19.84 (5.2)	15.7 (4.54)	18.06 (2.74)

1 significantly different than UBV, PON, PRU, HAS, WOO, H65, and H14 ($p<0.00005$)

2 significantly different than PRU, HAS, WOO, H65, and H14 (p,0.00005)

3 significantly different than PRU, HAS, WOO, and H14 ($p<0.00005$)

4 significantly different than PRU, HAS, WOO, and H14 ($p<0.00005$)

5 significantly different than PRU, and H14 ($p<0.00005$)

6 significantly different than PRU ($p<0.00005$)

7 significantly different than PRU ($p<0.00005$)

8 significantly different than DIX, UBV, PON, HAS, H65, and H14 ($p<0.0001$)

Table 3. Mean autumn functional group composition of eight sites of the main channel Buffalo National River. Means for each metric are followed by standard error in parentheses. Significant differences are indicated by a superscript. FG (functional group), SHR (shredders), SCR (scrapers), PRED (predators), CG (collector-gatherers), CF (collector-filterers). N=5. Alpha=05.

FG	DIX	UBV	PON	PRU	HAS	WOO	H65	H14
SHR	35.9 (10.69)[1]	3.14 (2.07)	0.97 (0.63)	5.07 (1.25)[2]	0.37 (0.09)	0.03 (0.03)	0.05 (0.03)	0.01 (0.01)
SCR	8.92 (3.41)[3]	37.29 (7.91)	44.62 (7.43)	22.19 (1.2)	15.79 (1.5)	11.93 (0.91)	46.53 (2.77)[4]	40.13 (2.73)
PRED	12.48 (2.03)	14.49 (4.85)	17.83 (4.11)	9.05 (2.7)[5]	24.48 (2.96)	16.59 (3.05)	11.57 (2.19)	11.95 (1.25)
CG	34.13 (7.97)	29.74 (8.07)	19.75 (2.53)	35.27 (5.21)	44.45 (2.41)	51.51 (5.32)	21.48 (3.86)	22.1 (1.76)
CF	1.57 (1.46)[6]	1.17 (0.68)[7]	15.46 (6.32)	26.94 (7.97)	13.79 (1.11)	19.01 (2.28)	19.77 (3.7)	24.85 (1.79)

1 significantly different than UBV, PON, PRU, HAS, WOO, H65, H14 ($p<0.00005$)

2 significantly different than DIX, PON, HAS, WOO, H65, and H14 ($p<0.00005$)

3 significantly different than UBV, PON, PRU, H65, and H14 ($p<0.00005$)

4 significantly different than HAS, and WOO ($p<0.00005$

5 significantly different than HAS ($p<0.0395$)

6 significantly different than PON, PRU, HAS, WOO, H65, and H14 ($p<0.00005$)

7 significantly different than PON, PRU, HAS, WOO, H65, and H14 ($p<0.00005$)

Table 4. Mean winter functional group composition of eight sites of the main channel of the Buffalo National River. Means for each metric are followed by standard error in parentheses. Significant differences are indicated by a superscript. FG (functional group), SHR (shredders), SCR (scrapers), PRED (predators), CG (collector-gatherers), CF (collector-filterers). N=5. Alpha=.05.

FG	DIX	UBV	PON	PRU	HAS	WOO	H65	H14
SHR	13.21 (4.26)[1]	0.81 (0.59)[2]	1.12 (0.56)[3]	15.21 (2.48)[4]	47.88 (5.54)[5]	32.23 (4.7)	37.32 (5.29)	14.36 (3.24)
SCR	17.56 (4.04)	41.41 (7.22)[6]	23.25 (2.52)	17.63 (1.71)	14.15 (1.93)	14.63 (2.43)	20.8 (1.4)	22.44 (6.8)
PRED	14.75 (2.95)[7]	22.09 (4.31)[8]	8.33 (0.67)[9]	3.84 (0.85)	3.51 (0.33)	8.1 (1.11)	5.71 (0.85)	6.82 (0.97)
CG	32.65 (2.96)	11.86 (3.4)[10]	38.6 (6.63)	28.95 (7.44)	23.69 (3.32)	41.13 (3.28)	27.47 (5.07)	45.26 (7.63)
CF	16.86 (7.16)	21.39 (7.25)	22.23 (6.3)	28.22 (3.43)	7.71 (0.8)	2.02 (0.58)[11]	5.25 (1.5)	5.4 (1.33)

1 significantly different than UBV, PON, HAS, WOO, and H65 ($p<0.00005$)

2 significantly different than PRU, HAS, WOO, H65, and H14 ($p<0.00005$)

3 significantly different than PRU, HAS, WOO, H65, and H14 ($p<0.00005$)

4 significantly different than HAS ($p<0.00005$)

5 significantly different than H65 ($p<0.00005$)

6 significantly different than DIX, HAS, and WOO($p<0.0075$)

7 significantly different than PRU, HAS, and H65 ($p<0.00005$)

8 significantly different than PON, PRU, HAS, WOO, H65, and H14 ($p<0.00005$)

9 significantly different than PRU, and HAS ($p<0.00005$)

10 significantly different than DIX, PON, WOO, and H14 ($p<0.0014$)

11 significantly different than UBV, PON, and PRU ($p<0.0001$)

Table 5. Mean spring functional group composition of eight sites of the main channel of the Buffalo National River. Means for each metric are followed by standard error in parentheses. Significant differences are indicated by a superscript. FG (functional group), SHR (shredders), SCR (scrapers), PRED (predators), CG (collector-gatherers), CF (collector-filterers). N=5. Alpha=05.

FG	DIX	UBV	PON	PRU	HAS	WOO	H65	H14
SHR	1.74 (0.48)	1.23 (0.38)	1.52 (0.59)	3.31 (0.75)	1.03 (0.29)	0.42 (0.23)	1.18 (0.41)	3.25 (2.14)
SCR	17.35 (3.57)	24.19 (3.55)	28.07 (2.68)	23.94 (1.93)	18.17 (1.4)	11.89 (1.5)[1]	15.46 (1.81)	23.08 (4.4)
PRED	21.07 (3.15)	30.82 (3.03)[2]	17.01 (1.33)	18.21 (2.21)	25.35 (3.37)	16.91 (1.38)	24.66 (3.68)	34.94 (4.56)[3]
CG	32.97 (6.07)[4]	33.9 (6.47)[5]	35.37 (3.69)[6]	41.66 (2)	35.52 (2.75)	67.74 (3.13)[7]	53.98 (3.87)	33.84 (3.24)
CF	24.73 (10.58)	4.25 (2.63)	11.98 (1.8)	7.93 (2.04)	16.05 (4.93)	2.28 (0.64)	4.54 (2.49)	2.59 (1.15)

1 significantly different than UBV, PON, and PRU ($p<0.0021$)

2 significantly different than PON, and WOO ($p<0.0015$)

3 significantly different than PON, and WOO ($p<0.0015$)

4 significantly different than WOO, and H65 ($p<0.0001$)

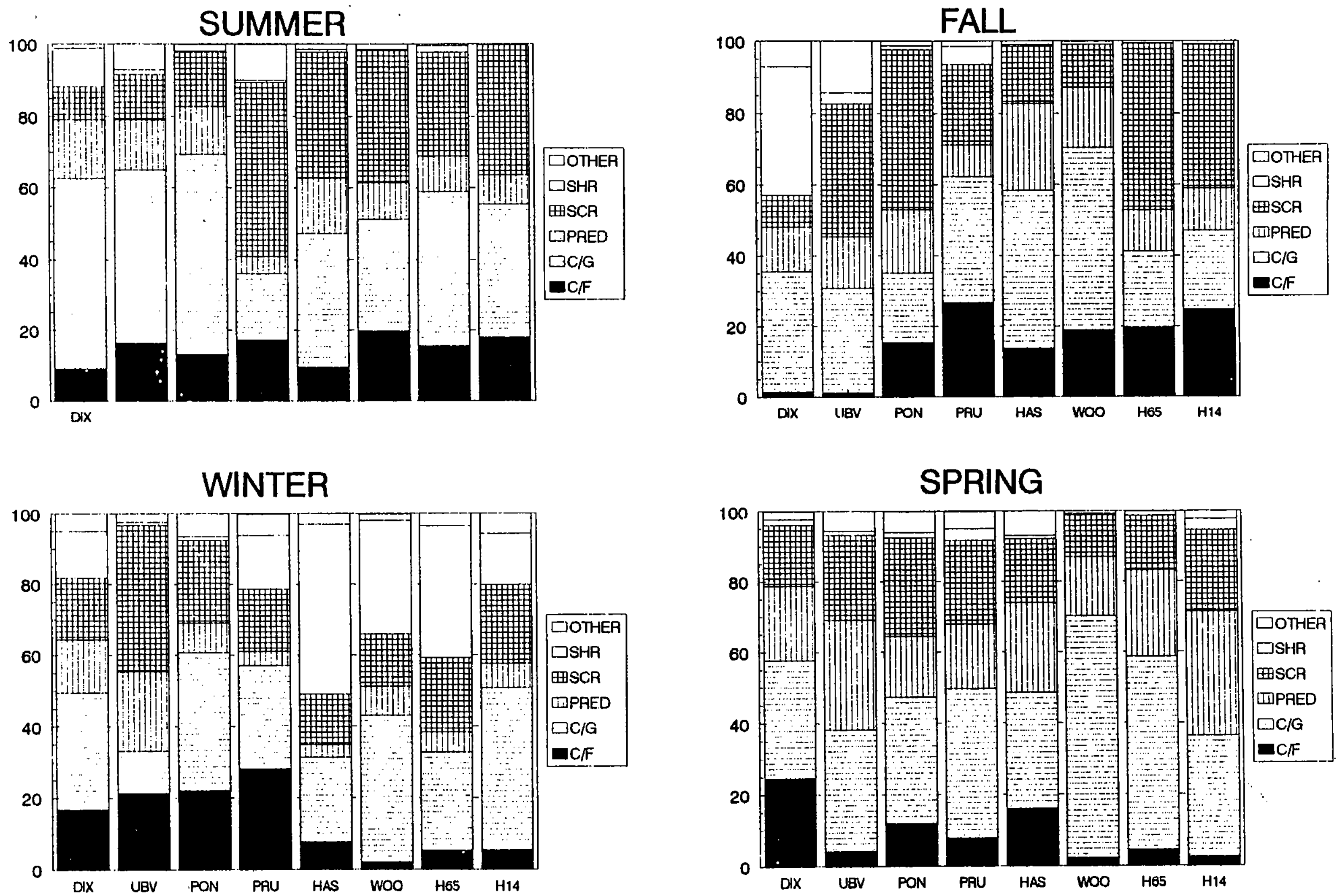
5 significantly different than WOO, and H65 ($p<0.0001$)

6 significantly different than WOO ($p<0.0001$)

7 significantly different than H14 ($p<0.0001$)

Figure 20. Proportions of six major functional groups for four seasons at eight sites along the Buffalo National River. SHR (shredders), SCR (scrapers), PRED (predators), C/G (collector-gatherers), C/F (collector-filterers), other (miscellaneous).

FUNCTIONAL STRUCTURE



generally increased downstream to UBV, PON, and/or PRU, decreased down to WOO, and then increased again. Predators comprised 10-30% of the total community at all sites except PRU where numbers were generally reduced. In winter predators were greatly reduced at all sites except DIX and UBV. In general, predators were more abundant during the autumn and spring than summer and winter. Relative abundances of collector-gatherers exhibited few differences among the sites but tended to be higher downstream during winter and spring, and were high at WOO in every season except summer. Collector-filterers were significantly more abundant downstream during autumn, and upstream during winter. There were no significant differences in collector-filterer relative abundance among sites during spring and summer.

Biotic Index Values

Biotic index values, calculated using the North Carolina Biotic Index (Lenat, 1993), were highly variable among sites in all seasons (Fig. 21). Some upstream sites had significantly lower values than downstream sites in autumn and winter. In spring, some downstream sites had significantly lower values than upstream sites. WOO had among the highest values in three seasons.

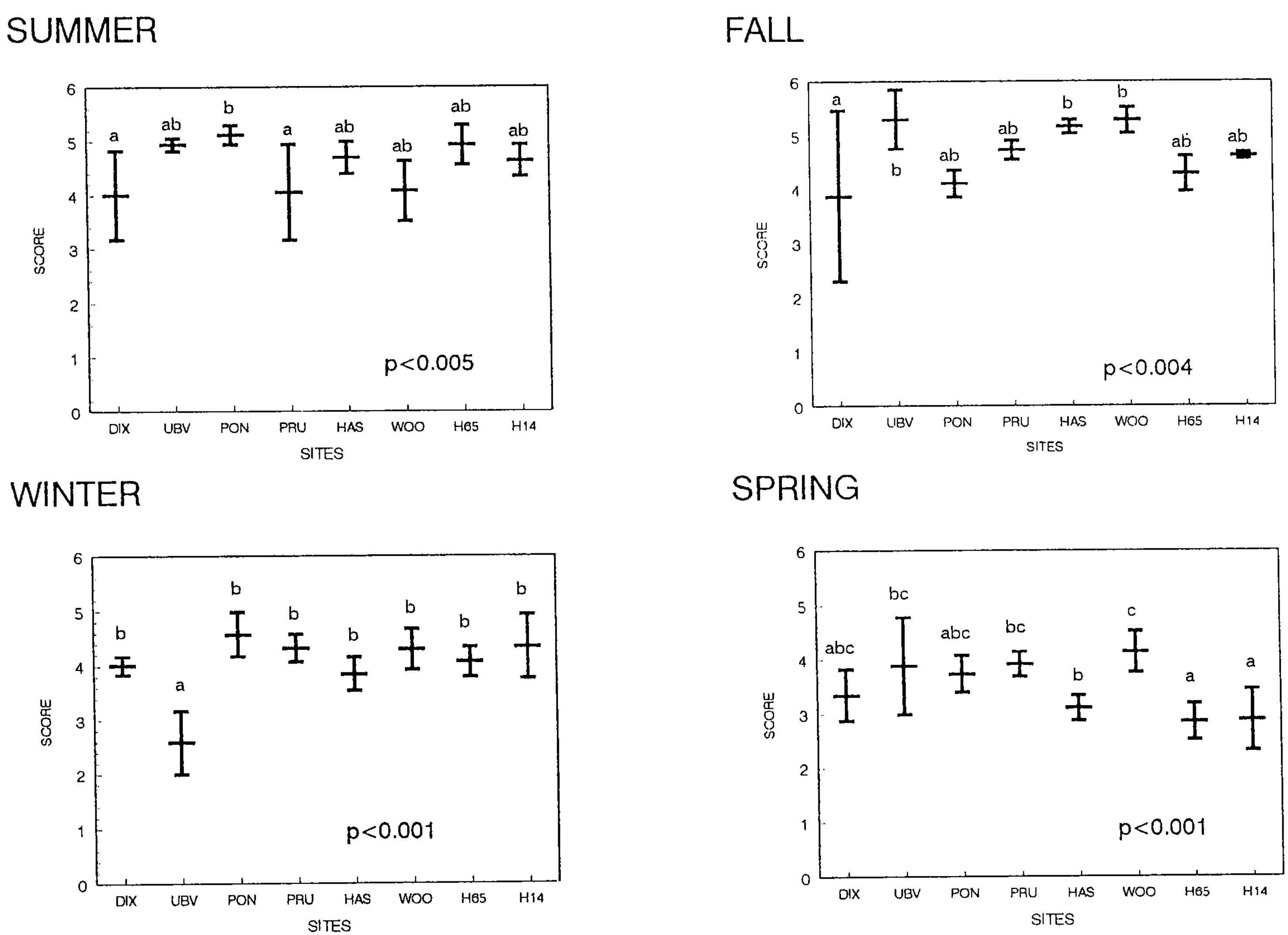
Correlational Analyses

There were no significant correlations between the chemical and microbiological metrics, and the measurements of community structure for summer, autumn and winter data.

Figure 21. Mean North Carolina Biotic Index (NCBI) values for four season at eight sites along the Buffalo National River. Error bars represent one standard deviation. Letters represent statistical differences. Sites sharing no letters are significantly different at $p<0.05$.

21

NCBI

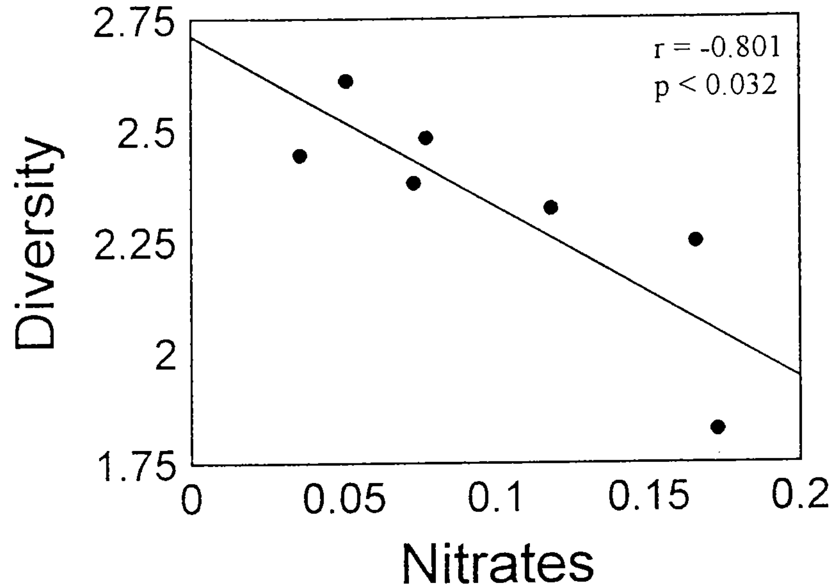

SUMMER
FALL
WINTER
SPRING
SCORE
SITES
DIX
UBV
PON
PRU
HAS
WOO
H65
H14
p<0.005
p<0.004
p<0.001
p<0.001

During the spring, strong negative correlations between nitrate nitrogen concentrations and Margelef's Richness Index ($r=0.-.801$; $p<0.04$), as well as between nitrate nitrogen and Shannon's Diversity Index ($r=-0.834$; $p<0.02$) were obtained (Figs.22 and 23).

Figure 22. Correlation between mean species diversity and mean nitrate nitrogen concentrations for the spring season at eight sites along the Buffalo National River.

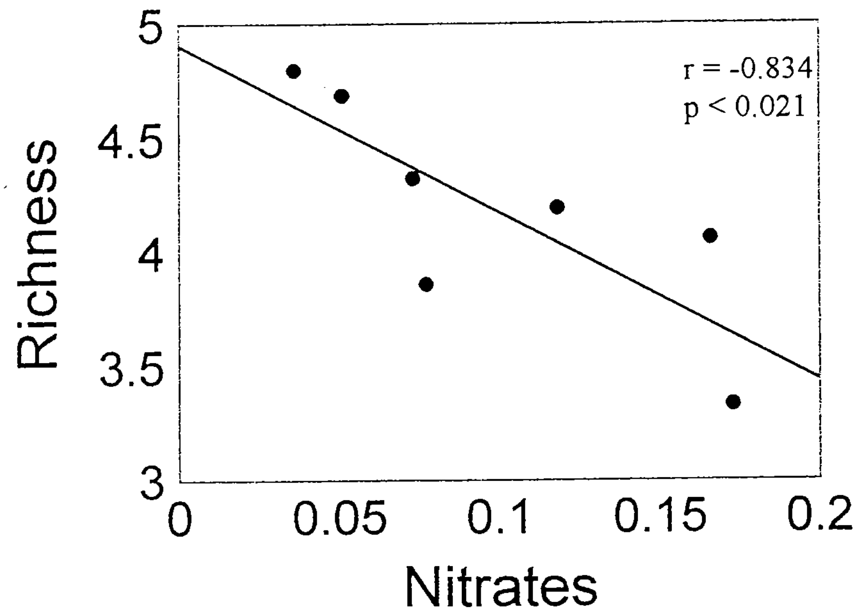
Figure 23. Correlation between mean richness and mean nitrate nitrogen concentrations for the spring season at eight sites along the Buffalo National River.

22



r = -0.801
p < 0.032
Diversity
2.75
2.5
2.25
2
1.75
0
0.05
0.1
0.15
0.2
Nitrates

23



r = -0.834
p < 0.021
Richness
5
4.5
4
3.5
3
0
0.05
0.1
0.15
0.2
Nitrates

Discussion

When proposing this investigation, I believed that water quality in the main channel of the Buffalo River was largely unimpacted by human disturbance and that the stream would be an excellent system in which to examine natural changes in community structure along a stream gradient. I hypothesized that a distinct transformation in community structure similar to that predicted by the River Continuum Concept (Vannote et al. 1980) would occur along the length of the river. Even though the sites selected included fourth and fifth order reaches only, measurements taken at the sites indicated that marked changes in physical characteristics (i.e., width, substrate size, percent canopy cover, percent emergent vegetation, discharge and link magnitude) occurred along the length of the stream. Chemical and microbiological data furnished by the U.S. National Park Service indicated that some degradation had occurred in two reaches of the river, but I believed that the level of pollution was so low that its impact on macroinvertebrate community structure would be negligible. However, my data indicate that significant changes in community structure have occurred in some portions of the stream and that these changes most probably result from anthropogenic disturbances. There are some indications that longitudinal zonation in the macroinvertebrate community occurs along the length of the river, but it is obscured by these human-induced changes.

Physical, Chemical and Microbiological Measurements

Extensive physical, chemical, and microbiological data (1990-1995) have been compiled by the U.S. National Park Service for all sites except DIX. The limited data available from DIX suggest that water quality at this site is very good as would be expected based on its location in an extensive block of the Ozark National Forest.

Qualitative observations and physical parameters measured at the sites suggest that the Buffalo River is typical of most streams with a riffle-pool geomorphology. Discharge increased steadily along the stream gradient and was significantly different when comparing upstream sites to those located further downstream. Water temperature also increased downstream. Although not measured quantitatively, stream width obviously increased downstream. Emergent vegetation increased downstream and canopy cover decreased downstream from PON. Also, the composition of the substrate changed dramatically with upstream sites being dominated by bedrock and larger substrates and downstream sites having much finer particles. Similar physical changes along the stream gradient have been reported from many unperturbed lotic systems (Culp and Davies, 1982; Hawkins and Sedell, 1981; Vannote et al., 1980; Cummins, 1977; ; Naiman et al., 1987; Bott et al., 1985; Minshall et al., 1985). Their occurrence in the Buffalo River suggests that corresponding changes in the biota also should be present as in other unperturbed streams (Statzner and

Higler, 1986).

Of the chemical measurements collected by the National Park Service, only pH, nitrates, and orthophosphates were significantly different among sites. Differences in pH along the river's length most probably reflect changes in the geology of different parts of the drainage basin. The watershed above UBV is predominated by sandstones and shale that have lower carbonate content and naturally result in lower pH than the dolomites and limestones present in the lower basin (Babcock and MacDonald, 1975; Mott 1991). Orthophosphate concentrations at all sites were relatively low compared to streams receiving large amounts of phosphate pollutants (Lemly, 1982; Stewart and Robertson, 1992), but were significantly higher at UBV than the four most downstream sites. Again, these differences most probably occur naturally. Numerous investigations indicate that phosphorous concentrations are naturally higher in headwaters than more downstream sites (Mulholland et al., 1995; Mulholland and Rosemond, 1992; Newbold et al., 1983).

Unlike pH and orthophosphates, significantly higher nitrate concentrations at WOO during winter compared to UBV and PRU and marginally higher concentrations at H65 probably are not the result of natural processes. They likely result from increased nutrient loads carried into the main channel from some tributaries. Large portions of many tributary watersheds feeding the middle section of the river near WOO have been converted into pasture to support livestock-rearing operations (Mott, 1991). Wastes produced by cattle, swine, and other domesticated animals have high nitrogen concentrations (ammonia, urea, nitrites, etc.) that are converted into nitrates which can enter the river through groundwater and runoff (Hem, 1985). Tributary inputs (including nutrients) into master streams can have significant influences on trophic structure and other community characteristics (Vannote, 1980; Minshall et al., 1985; Statzner and Higler, 1985). At PON, mean annual nitrate concentrations were only marginally higher than those upstream (UBV) and downstream (PRU). Beef cattle operations in the Boxley Valley Historic District are concentrated in the floodplain of the river a short distance upstream from this site. Because ammonia, urea, and other nitrogenous wastes require considerable time before they are oxidixed into the nitrate form (Hem, 1985), recorded nitrate concentrations at PON may indicate that sufficient time for oxidation is not occurring, or that there are insignificant inputs of organic nitrogen occurring there. Nitrite and organic species of nitrogen (which were not monitored at a sufficient interval to be analyzed in the present investigation) are unstable and short-lived in aerated water and are considered indicative of nearby sources of organic pollution. Nitrate is also indicative of organic pollution, but generally from sources that are substantial distances from sampling sites (Hem, 1985). If this is true, one might expect nitrate concentrations at PRU to be higher, which they weren't, perhaps because of uptake and dilution of what were relatively low nitrate concentrations.

Like nutrient concentrations, fecal coliform bacteria also are indicative of organic pollution (by endothermic animals) and are used routinely in water quality analyses. However, fecal coliforms generally occur in highest concentrations near the source of organic wastes and decrease dramatically downstream (Davenport et al., 1976). During the present investigation, fecal coliform values were significantly higher only at PON compared to all other sites sampled. This might seem somewhat surprising considering that nitrates were highest at WOO and one might expect fecal coliforms to be highest there also. This indicates that the high nitrates at WOO may be the result of upstream tributary inputs, and that cattle manure at PON and WOO is not significantly responsible for the observed nitrate concentrations. Higher fecal coliforms and lower nitrate concentrations at PON probably are indicative of unpolluted tributaries entering the river upstream from this site and the close proximity of fecal inputs from cattle in the Boxley Valley area.

Abundance

There were few significant differences in abundance among sites in different seasons, but values were higher at middle and downstream sites for substantial parts of the study period. Lemly (1982), found that total abundance as well as densities of dipterans increased in an organically-enriched stream reach. Increased numbers of dipterans, primarily chironomids, were largely responsible for the high abundance at WOO. The few significant differences exhibited by this metric were probably the result of a high degree of spatial variability among sites.

Taxa Richness and Diversity

Taxa richness and diversity give an indication of community complexity and are generally higher at sites experiencing little or no anthropogenic disturbance compared to more disturbed sites (Lenat, 1983; Cargill and Harp, 1987; Richards and Minshall, 1992). Although significantly lower richness and diversity occurred at DIX compared to more downstream sites, these differences probably resulted naturally. The DIX site is fourth order, but it is third order immediately upstream and exhibits numerous characteristics of a headwater stream. The substrate is dominated by bedrock and large boulders, and the narrow stream width facilitates energy inputs that are predominated by allocthonous organic matter. Also, the geology and high stream gradient in this reach result in extreme scouring by spates and intermittent flow conditions during the summer and autumn. The combination of spatial homogeneity and extreme temporal variability has been shown to reduce the influence of biotic interactions (e.g., competition and predation), which depending on the magnitude of the disturbance could increase or reduce species diversity in stable environments (Vannote et al., 1980; Resh et al.1988; Poff and Ward, 1989; Ziser, 1985; Flecker, 1992). The low richness and diversity at DIX could partly be due to the severity of these disturbances, which may be of such magnitude that much of the biota is lost during each event. However, these events are generally within the normal annual hydrologic regime, and would be considered disturbances infrequently (Resh et al., 1988). Even if that is true, research suggests that regular and severe disturbance events help shape community structure over time and may lead to the evolution of communities with restricted numbers of taxa possessing the adaptations necessary for persistence in harsh environments (e.g. burrowing and other refuge seeking behavior, diapause, aestivation, short life cycles, rapid recolonization rates, asynchronous development and emergence) (Gray, 1981; Gray and Fisher, 1981; Power et al., 1988; Poff and Ward, 1989).

Downstream from DIX, richness and diversity initially increased as predicted by the RCC. However, the marked decline in the value of these metrics at HAS and WOO and the contrasting increase in %DOM (primarily chironomids) during three seasons were unexpected, especially in a stream considered to be relatively pristine. These two sites are fifth order, spatially heterogenous riffles and were expected to exhibit the highest values of all the sites for these metrics (Vannote et al., 1980). If richness and diversity had peaked upstream from HAS and declined continuously downstream from there, I would have concluded that the midreach peak for these metrics had occurred upstream from where I predicted. However, downstream from WOO, the values for richness and diversity increased, possibly indicating a recovery zone from disturbance occurring between PRU and WOO. The dramatic decline in metric values from PRU to WOO, and the increasing values from WOO to H65 are unlike the more gradual longitudinal changes reported from other relatively natural systems (Minshall et al., 1983; MacFarlane, 1983) and advanced by Vannote (1980) and Cummins (1977).

Strong negative correlations of richness and diversity with nitrate concentrations during spring suggests that nonpoint source pollution may be changing the natural continuum in lotic community structure in this reach, an accepted phenomenon among stream researchers (Resh et al., 1988; Crunkilton and Duchrow, 1991; Minshall et al., 1985; Vannote et al., 1980).

Time restrictions prevented the identification of chironomids beyond the familial level. This may have produced biased richness and diversity values, that otherwise may have been higher. Some researchers suggest that the use of macroinvertebrates as indicators of water quality requires species level identifications because many genera contain species with far different pollution tolerances (Resh and Unzicker, 1975). However, Lenat (1983) demonstrated that in moderately polluted streams, identifying chironomids beyond the familial level can confound interpretation of diversity and richness indices because chironomid diversity often increases while that of other taxa decreases. Although the fecal coliform concentrations at PON and nitrate concentrations from WOO were significantly higher at certain times of the year than at some other sites, they were relatively low compared to other streams in northwest

Arkansas, and represent no worse than slightly polluted conditions.

Taxonomic Composition

The number of EPT taxa, %EPT, and EPT:D exhibited a trend similar to that of richness and diversity, and also may be indicative of a change in community structure at HAS and WOO brought about by increased nitrate concentrations. As mentioned previously, headwater conditions and relatively severe disturbances at DIX are probably responsible for the low values of these metrics at that site (Vannote et al., 1980; Power et al., 1988; Bruns et al., 1987; Lenat, 1996).

The relatively high fecal coliform concentrations collected from PON suggest that there is a significant amount of organic pollution entering the stream in this reach, but there were no significant correlations between these metrics and fecal coliform concentrations.

Dipterans were proportionally more abundant at DIX than all the other sites. At sites further downstream this might indicate degraded water quality, but at DIX there are no known sources of significant pollution. A significant number of the dipterans at DIX were shredders, principally tipulids (highest numbers of which occurred in winter), but the majority were chironomids and simuliids (which occurred in substantial numbers at upstream sites during periods of adequate discharge). These results suggest that headwater streams with naturally high disturbance regimes may be dominated by dipterans rather than the EPT taxa. Perhaps the short life cycles characteristic of many dipterans (especially chironomids) favors their existence in high disturbance environments. If dipterans are resistant to anthropogenic disturbance, they may also be more tolerant to natural disturbances compared to the EPT taxa.

The high percentages of chironomids in samples from WOO in autumn, winter, and spring indicate possible degradation of water quality that could be the result of higher nitrates in this reach of the river. Other investigations have established that streams receiving higher than normal nutrient inputs exhibit reduced richness and diversity (especially of EPT taxa) but the abundance and percentage of dipterans (especially chironomids) in samples increases (Lemly, 1982; Brown et al., 1983; Stewart and Robertson, 1992). Lenat (1983), stated that grazing chironomids may fare well in moderately polluted environments due to the increased availability of algal food, but EPT competitors and Gastropoda may be reduced.

Seasonal Trends in Abundance, Richness, Diversity, and Community Composition

Distinct shifts in community structure occur seasonally in streams of the temperate zone (Doledec, 1989; Boulton et al., 1992). During the present investigation, community structure differed extensively with season. Abundance was significantly higher in summer and autumn than in winter and spring at most sites. Hawkins and Sedell (1981) noted a similar pattern in four Oregon streams and suggested that high abundances in the autumn were probably due to recently hatched early instars. This recruitment originates from both fast and slow-seasonal, univoltine, cool-season species (e.g. Plecoptera) which remain in an egg or early instar diapause during the period when water temperatures are higher, hatch with decreasing water temperature, and then complete development before water temperatures rise significantly during the late spring/early summer (Merritt and Cummins, 1984; Stewart and Stark, 1988). Summer abundance was high most probably as a result of the presence of multivoltine taxa, such as the Chironomidae, Simuliidae, Baetidae, and Caenidae, which exhibit various fast-seasonal or nonseasonal life history cycles (Merritt and Cummins, 1984). These groups contain species that produce two or three overlapping cohorts within a few months, experiencing higher recruitment than mortality. These species emerge in spring through late fall whereas cool water univoltine taxa recruitment is greatest in the autumn, with mortality increasing progressively in winter through spring (Merritt and Cummins, 1984). Abundance in this investigation was the lowest in winter, and could possibly be the result of high mortality of recently hatched instars as proposed by Hawkins and Sedell (1981), or large-scale emergence in late autumn, or a combination of both. Research on net-spinning Trichoptera of the Mulberry River, Arkansas, indicated that autumn emergence in this group ends in October, begins again in April, and that overwintering larvae were primarily mid to late instars (Bowles, 1989). Although the size of the organisms collected in this investigation was not

measured, high mortality rates of early instar specimens and a corresponding increase of resources for surviving individuals in the autumn to winter transition period could account in part for the reduced abundance and relatively large size of organisms observed in winter samples.

Spring was significantly more rich and diverse than summer and autumn, reflecting a large number of newly hatched EPT from overwintering eggs. Doledec (1989) observed a similar trend in a mediterranean river and called spring a 'seasonal ecotone', during which species richness and diversity reached their maximums. The low values for these metrics in autumn are probably the result of high numbers of a few multivoltine summer species and newly recruited autumnal species which would reduce evenness.

Functional Group Metrics

Few significant differences in functional group composition were observed along the longitudinal gradient of the Buffalo River. The most pronounced difference was the number of shredders which were far more abundant upstream than downstream in summer and autumn. In winter, shredders were generally abundant at all sites, possibly because of downstream export and local inputs of leaves that may provide the necessary food resources to sustain a downstream population of shredders this time of year. Although this has apparently not been reported previously, other studies point out that seasonal, site specific interruptions in stream zonation do occur (Bott et al., 1985; Minshall et al., 1983).

There were no significant differences among sites in amounts of cobble substrate, and in winter these cobbles nearly always had some CPOM trapped against their upstream sides (personal observation). In spring, numbers were depressed at all sites, probably because of the scouring effects of springtime spates which may largely eliminate their food resources (leaves and other organic debris). The generally high abundance of shredders at DIX further supports the conclusion that it is a headwater site and can be compared to the other sites only from a perspective based on longitudinal zonation. Shredders occur in greater numbers in headwaters due to the large allocthonous inputs in these reaches (Vannote et al., 1980; Cummins, 1977; Brussock and Brown, 1991), and the retentive nature of boulders and debris dams found there (Naiman et al., 1987; Bilby and Likens, 1980; Bretschko, 1990).

At PON, the substrate is primarily cobble and gravel and the stream is wider, with less retention capacity than DIX and UBV. This may account for the numerical importance of scrapers at this site compared to upstream sites. In warmer months, these scrapers were comprised primarily by coleopterans, baetid, caenid and heptageniid mayflies which were replaced in colder months by certain plecopterans (Haploperla and Strophopteryx) and Agapetus illini (Trichoptera). The significantly greater numbers of scrapers at PON than at HAS and WOO did not fit the predictions I made. I believed that scrapers would be more abundant at HAS and WOO than at PON because these sites are much wider and should be more exposed to sunlight. Since chironomids weren't identified beyond the familial level, they were classified as 90% collector-gatherers, and 10% predators (Merritt and Cummins, 1996), resulting in at least a portion of them being classified incorrectly. Some of the collector-gatherers at WOO may have been chironomid grazers (scrapers) that according to Lenat (1983), often increase under moderately polluted conditions. Although chironomid larva span many trophic categories, a review of Merritt and Cummins (1984) indicates that most are facultative collector-gatherers. Studies have shown that disturbance in the form of nutrient loading can lead to changes in community structure that include shifts in overall community trophic function from shredders and scrapers to collector-filterers and collector-gatherers (Tuchman and King, 1993). In addition, polluted environments favor rapidly reproducing 'r' strategists with short life cycles such as many species of chironomids (Lenat, 1983).

Biotic Index Values

Biotic index values varied widely among sites. Highest values occurred at WOO, followed by PON and PRU. Higher biotic index values indicate that there are relatively large numbers of pollution tolerant specimens present (Hilsenhoff, 1987; Lenat, 1993). Substantial numbers of chironomids were collected from WOO and PON at different times of the year. The family Chironomidae was treated as one taxonomic group, and as such were assigned a mean biotic index value derived from the biotic index values of all the chironomid species (130) included in the North Carolina Biotic Index (Lenat, 1993). The result of this was the placement of the chironomidae as a group in the facultative tolerance range as opposed to the intolerant or tolerant tolerance range, an oversimplificaton of the actual tolerance values for the various representatives of this group. Because the relative abundances of chironomid species and their corresponding biotic index values in this investigation are unknown, no concrete inferences can be made regarding the impacts of higher numbers of fecal coliform bacteria or nitrate concentrations on the sampled macroinvertebrate community, using the North Carolina Biotic Index. If the chironomids had been identified beyond the family level, the biotic index values of all the sites may have been either higher (indicating impairment of the community) or lower. In spite of this, the large numbers of chironomids at PON and WOO had an obvious effect on the biotic index values obtained for these two sites, and although DIX had more chironomids than PON, the presence of many pollution intolerant taxa at DIX resulted in it having the lowest annual biotic index value of all the sites. This is another indication of possible water quality impairment at PON and further downstream, most notably at WOO.

Correlational Analyses

The strong negative association between taxa richness and diversity, and nitrate concentrations during spring indicates water quality impairment may have occurred in parts of the Buffalo River. The reaches of the river that appear to be the wastes on privately owned fields bordering the protective corrider of the park. Other investigations have demonstrated that nutrients are released into receiving waters in greater amounts in agricultural areas than in forested areas (Likens and Borman, 1974; Tuchman and King, 1993) and that benthic densities (abundance) are higher in streams flowing through urban and agricultural land (Corkum, 1992; Minshall et al., 1983; and Bott et al., 1985). Abundance was highest at WOO and although there was no significant association between nitrate concentrations and the percentage of samples that were composed of chironomids, there were more chironomids in samples collected from WOO than from any other site, and the relatively high abundance of the chironomidae at WOO were responsible for the overall increased abundance at this site.

Conclusions

One of the objectives of this investigation was to evaluate the River Continuum Concept along fourth and fifth order reaches of the Buffalo National River. Most evaluations of the RCC have been conducted along reaches of streams encompassing a wider range of stream orders than were examined during this investigation (Bott et al., 1985; Brussock and Brown, 1991; Hawkins and Sedell, 1981; and Minshall et al., 1983; Naiman et al., 1987), but not all (Bruns and Minshall, 1985; MacFarlane, 1983). Although only two stream orders were included in this investigation, there was an obvious transformation in physical habibtat from DIX to H14, and the prediction of conformity with the RCC was based on the visual observations that later were confirmed with measurements of physical habitat. The only functional groups that strongly conformed to the RCC were shredders and predators, but organic pollution resulting from local land use practices may have effected the macroinvertebrate community of one reach of the river in ways that interrupted normal longitudinal zonation patterns. This was indicated by the unexpected trends in taxa richness and diversity as well as the taxonomic composition metrics.

The second and third objectives of this investigation consisted of conducting a baseline inventory of the macroinvertebrate community of the Buffalo River, in an effort to document the community prior to and in light of increasing environmental pressure within the river's watershed, and to determine if the macroinvertebrate community indicated any possible water quality degradation. Increasing agricultural activities and other types of development within the watershed could affect the water quality of the river and lead to changes in community structure. Comparisons of data collected in the future with the results of this investigation will enable the responsible resource managers to monitor changes occurring in the Buffalo River, as well as in other streams in the Ozark Highland physiographic region, and to develop and implement protective strategies.

The results of this investigation indicate that the macroinvertebrate community in one reach of the Buffalo River has been affected significantly by declining water quality, probably because of land use practices within the watershed. Some of the physicochemical and macroinvertebrate community structure data were significantly and negatively different from what would have been predicted in the absence of anthropogenic disturbance..

The data presented in this investigation indicates that the use of macroinvertebrates is an important component of any water quality evaluation due to the sensitivity of this community to relatively minor changes in water quality.

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